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THE PRE-CARBONIFEROUS EXOTIC BOULDERS IN THE SO-CALLED "CANEY SHALE" IN THE NORTHWESTERN FRONT OF THE OUACHITA MOUNTAINS OF OKLAHOMA

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ABSTRACT

A new explanation is offered for the "glacial boulders" in the so-called "Caney shale" of the Ouachita Mountains. Their glacial character is disputed. They are considered exotic blocks in the frontal nappe of the Ouachita structure, comparable, in particular, to the Flysch blocks of the frontal Alpine thrust sheets.

In another paper[1] the writer has discussed the structure of the Ouachita Mountains of southern Oklahoma and Arkansas, and advanced the opinion that these exposures represent only a small frontal portion of a greate arcuate mountain complex of Alpine structure, skirting the entire southeastern rim of the Laurentian Plateau. The exposed zone is composed of a pack of great nappes, pushed far to the northwest, out of a central area, now deeply buried under the Cretaceous cover of the Gulf Coast Plain. The overthrust mass is composed of old-Paleozoic formations in a facies that is entirely foreign to that of the equivalent strata, as developed on the foreland, the Mid-continent Plateau. In addition, the nappes contain a great thickness of latest Mississippian to early Pennsylvanian sediments, developed in an orogenic Flysch facies. All these rocks must origi-

[1] "Permo-Carboniferous Orogeny in South-Central United States," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. XV (September, 1931), pp. 991–1057.

nally have been deposited in a wide intercontinental geosynclinal area, off the continental plateau of North America. In front of the mountains a wide foredeep developed, which was filled with Lower Pennsylvanian erosion detritus of the Ouachita ranges, in Molasse facies.

The orogeny occurred in two distinct pulsations, extending from latest Mississippian to post-Morrow time, followed by posterior disturbances of a minor order which may have extended well into the Permian. The final paroxysm of the advancing overthrusts must have been concluded after the last orogenic phase, which affected the distinct Wichita Mountain system late in the Pennsylvanian and raised the Arbuckle Mountains. The overthrust masses have carried on their back deposits of early Pennsylvanian age, laid down in intra-montane basins (the intra-Ouachita Atoka), at the same time that the Molasse was deposited in the foredeep fringing the front range, later, in part, overthrust by the same nappes.

The writer has also developed the theory that these thrust sheets overran the southeastern prolongation of the Wichita and Red River mountains, which pass underneath, and therefore constitute the autochtone of the Ouachitas.

For further details the reader is referred to the above-mentioned paper and the cited bibliography, and also to a more extensive treatise published (in the English language) in the *Proceedings of the Royal Academy of Sciences of Amsterdam.*[1]

DESCRIPTION

In the frontal zone of the Ouachitas of Oklahoma (not of Arkansas), between the Ti Valley shear plane and the Winding Stair overthrust, and farther south, in the western portion of the mountains, but in no place south of the Octavia thrust plane, narrow outcrops occur of a locally macerated black shale, some few hundred feet thick, intercalated between masses of Atoka formation and Jackfork sandstone, each of which is some 4,000 to 6,000 feet thick. This shale is generally called the "Caney" in the literature and on the geologic map of Oklahoma. Its real stratigraphic meaning and correlation are in dispute.

[1] "The Permo-Carboniferous Orogeny in the South-Central United States," *Proc.* Sec. II, Vol. XXVII, No. 3 (1931).

Elsewhere[1] the writer has already discussed the conditions pertaining to the foreland Caney, and the confusion about the term "Caney," which designates a different sequence in the Arbuckle region, in the Ardmore Basin, in the Ouachita foreland, and within the Ouachita thrust sheets. Recapitulating this shortly: the foreland Caney, as developed in the Arbuckle region, overlies the Sycamore limestone, which latter, according to Ulrich, represents the upper part of the lower Mississippian Kinderhook division. The Arbuckle Caney represents lowermost Pennsylvanian, as well as Mississippian; the lower portion is, according to Ulrich, separated from the upper part by a break.[2] This upper Caney would be lowermost Morrow and may, in part, be only an equivalent of the Wapanucka limestone. Ulrich places the basal portion of this Caney in the Middle Mississippian (Meramec). This may be too low. In the writer's opinion, this entire Arbuckle Caney is probably representative of the complete Stanley-Jackfork Flysch sequence of the Ouachitas; the outer northwestern randzone of the deposits of the Flysch geosyncline.

In the Ardmore Basin we have a transition development: the 5,000-foot-thick Caney-Springer sequence, which also, apparently, represents the Ouachita Flysch, but closer to the source region, less fine grained, and already considerably thicker.

In the autochtone, in front of the Ouachita Mountains, north of the Ti Valley thrust plane, there is also a Caney, very similar to that developed in the Arbuckle region, and probably representing the same outer randzone. No Jackfork is yet represented between the Ti Valley and Choctaw faults. This foreland Caney of the Ouachitas underlies the foreland Atoka, and the Wapanucka limestone, where the latter is represented. There is no Wapanucka, at least no Wapanucka developed as the typical limestone, on the nappe south of the Ti Valley thrust; also, there is none farther to the east in Arkansas. In the Arkansas section the Atoka rests on Jackfork, which must be within the overthrust mass; it is the intra-Ouachita Atoka.

[1] *Bull. Amer. Assoc. Petrol. Geol.*, Vol. XV (September, 1931), pp. 991–1057.

[2] E. O. Ulrich, "Fossiliferous Boulders and the Ouachita Caney Shale Containing Them," *Okla. Geol. Surv. Bull. 45* (1927), p. 25.

South of the Ti Valley fault, we suddenly encounter the entire Stanley-Jackfork Flysch, between the intra-mountainous Atoka and the Novaculite. It is here that the thin band of Ouachita "Caney" intercalates between the Jackfork and the Atoka. In the Arkansas section, this "Caney" does not exist; farther on the nappes, south of the Octavia shear, it is also absent in the Oklahoma section, and the intra-Ouachita Atoka overlaps directly over older rocks. A fauna of Morrow age, however, continues in the base of this latter Atoka.

The lithologic characteristics of the "Caney" shale are the same in all Ouachita locations: a black, locally much-crushed shale, filled with small round, marble-like phosphatic nodules, and occasional larger limestone concretions. G. H. Girty, cited by Miser,[1] states that the fauna of all the exposures is also similar, indicates Mississippian age, and presents only regional differences from the Mississippian part of the foreland Caney. Sidney Powers[2] states that the shale contains many micro- in addition to some macro-fossils, and that the first indicate post-Chester but pre-Pottsville age, according to B. H. Harlton.

The southern exposures of the certainly uppermost Mississippian Stanley shale show that sandstone ledges, increasing in thickness and clasticity toward the south, finger out toward the north. The relatively thin "Caney" of the Ouachita nappe cannot possibly be the equivalent of the entire foreland Caney as such, which probably represents the complete Flysch section. It can only represent a comparatively thin layer of a more persistent shale, probably of general lower Caney age, in a part of the Flysch section, which has not only become far thicker but has also turned largely arenaceous. This shale is now intercalated between the massive Jackfork sandstone and the intra-Ouachita Atoka formation. Overlapping is suspected by some geologists. If the contact is normal, it would represent about the time of our second pulsation of the Wichita orogenic phase.[3]

[1] H. D. Miser and C. W. Honess, "Age Relations of the Carboniferous Rocks of the Ouachita Mountains of Oklahoma and Arkansas," *Okla. Geol. Surv. Bull. 44* (1927), p. 27.

[2] "Age of the Folding of the Oklahoma Mountains; the Ouachita, Arbuckle and Wichita Mountains of Oklahoma and the Llano-Burnet and Marathon Uplifts of Texas," *Bull. Geol. Soc. of Amer.*, Vol. XXXIX (1928), p. 1040.

[3] *Amer. Assoc. Petr. Geol. Bull.*, Vol. XV (September, 1931), pp. 991–1057.

In this relatively thin bed of shale (never in the autochtone Caney north of the Ti Valley shear) numerous boulders and also far greater blocks of foreign rocks occur. They are found in a zone about a hundred miles long in the northwestern section of the mountains in Oklahoma; they have never been mentioned from Arkansas, where this "Caney" shale intercalation is not represented. The boulders and blocks represent samples of the complete section of pre-Carboniferous sedimentary rocks of the Arbuckle sequence, a series which is entirely foreign to the Ouachita section. They consist mostly of compact limestones, but sandstones and even arenaceous and calcareous shales (these mostly in small pieces) are observed. Pre-Cambrian rocks do not occur.

The erratics are found imbedded in the shale, but those seen are mostly weathered out and strewn over many of the bare outcrops of the lower part of the shale band.[1] By the fossils contained in the pieces the following formations have been identified: Cambrian-Ordovician Arbuckle limestone (very abundant), Ordovician Simpson and Viola limestone, Silurian Sylvan shale and Chimneyhill oölite, Devonian cherts, some shales of Sycamore (Lower Mississippian) age, a light-gray calcareous shale with Morrow fossils, and also a crinoidal limestone, equally with a Wapanucka (Morrow) fauna. As already stated, granite or other crystalline or metamorphic basement rocks do not occur.

All these fragments, with the possible exception of some of the Devonian cherts, can only have originated from formations which are wholly absent in this facies in the Ouachita system, but they represent the complete sequence of the Arbuckle province, excepting only the granite and the basal Cambrian Reagan sandstone. As Ulrich points out,[2] many of the rocks are typically Arbuckle, different from contemporaneous formations represented anywhere in this entire region.

Miser describes the boulders and pebbles as irregularly scattered through the shale "like plums in a pudding," not at all like an ordinary boulder bed or conglomerate.[3] The fragments are of many

[1] E. O. Ulrich, *op. cit.*, p. 7. [2] *Ibid.*, p. 9.

[3] H. D. Miser, "Structure of the Ouachita Mountains of Oklahoma and Arkansas," *Okla. Geol. Surv. Bull. 50* (1929), p. 28.

sizes: some are mere pebbles a fraction of an inch in diameter; many blocks measure 10 feet in their longest dimension, and others as much as 200 feet; one measured by Miser was 50×369 feet. Sidney Powers mentions a Viola limestone block measuring 60×550 feet.[1] The larger blocks may be even greater than stated, being not fully exposed. All the largest blocks, so far described, occur in the Johns Valley exposure.

The pieces are subangular or rounded, and most of them appear weathered or corroded by solution. In some of the outcrops, smaller pieces have been squeezed out and elongated into lenticular shapes by pressure; many boulders are slickensided, and not infrequently gouged.

These exotics appear in streaks in a partly mylonitized shale, thus giving the appearance of boulder "beds." Sidney Powers drew the writer's attention to the fact that by no means all this "Caney" shale appears highly crushed. He has studied localities where the shale "inclosing the famous boulders" is neither macerated nor mylonitized.[2] Miser describes shale beds from Johns Valley which are in every way lithologically similar to foreland Caney and show no signs of mylonitization or mixture with other material; such shale overlies the boulder horizon, which is confined to the lower 50–100 feet of the shale.[3] At other localities there are three or four boulder-bearing horizons; elsewhere again, there are no boulders in the lower black shale, but in an overlying gray shale. "Caney" micro-fossils occur in shales below the most abundant boulder-zones.[4]

It seems evident, therefore, that the entire mass of the Ouachita "Caney" is not a thrust-plane mylonite, but that considerable masses of a sedimentary, more or less undisturbed, shale are present. The streaks of exotics do not occur in any regular "bed," but their place in the shale varies.

Although the Johns Valley locality has been best described in the literature, similar blocks have been recognized along the entire belt of "Caney" outcrops, as far east as Stapp in LeFlore County, near

[1] *Op. cit.*, pp. 1031–72.

[2] Written communication of December, 1930.

[3] H. D. Miser and C. W. Honess, *op. cit.*, pp. 22–23.

[4] Sidney Powers, *op. cit.*, p. 1043.

the Arkansas line. They have never been described from Arkansas localities. Concurrence of opinion, excepting Ulrich, gives the matrix Mississippian age. Powers cites macro- and micro-fossils; the latter occurring both above and below the most abundant boulder-bearing horizon. The micro-fossils are post-Chester and pre-Pottsville in age, according to Harlton.[1] Miser and Girty[2] cite Mississippian fossils as evidence, chiefly from calcareous concretions; Ulrich, however, considers these as much *remanié* as the exotic fragments (this could scarcely apply to all of the micro-fauna). Consequently, Ulrich wishes to place the shale in the Lower Pennsylvanian, higher than the youngest boulders identified in it (Morrow). He considers the blocks and boulders sedimentary erratics, transported by shore ice, and hence the matrix must not be older than any of the boulders. He, therefore, proposes to change the name "Caney" to "Johns Valley shale." The writer also thinks it just as well not to call this shale "Caney," regardless of its age.

The exotics occur only in those localities where the shale matrix is intercalated between Atoka and the great Jackfork sandstone, and never in the autochtone true Caney, resting normally on Sycamore limestone. Even within the Ouachita Mountains these erratics do not occur in the autochtonous belt south of the Choctaw fault. They do not occur in the Brushy Creek inlier, in Sections 4 and 5, T. 2 N., R. 15 E. They only set in abruptly and in great abundance in the bands of shale on the flanks of Winding Stair Mountain, that is, south of the Ti Valley shear plane. The first of these occur about 3 miles south of the Brushy Creek exposures.[3] The principal localities where the exotics occur are marked on Ulrich's map.[4]

In addition to these "Caney" zones of blocks, other layers occur. Some of these seem to be more or less normal conglomerates; others not. G. D. Morgan[5] and B. F. Wallis,[6] cited by Ulrich, mention occurrences of erratic boulders in shales and limestones, referred by them to a Morrow (Wapanucka) horizon. Powers also mentions

[1] *Ibid.*, p. 1040.

[2] *Op. cit.*, pp. 25–26.

[3] E. O. Ulrich, *op. cit.*, p. 42.

[4] *Ibid.*, Fig. 1, p. 13.

[5] "Stratigraphic Position of the Franks and Seminole Formations of Oklahoma," *Okla. Geol. Surv. Circ. 12* (1923), p. 10.

[6] *Okla. Geol. Surv. Bull. 23* (1915), pp. 69–72.

such. They occur a considerable distance to the northwest of the Brushy Creek exposure, therefore apparently in the autochtone; and they are not associated with large blocks. They also occur farther east in LeFlore County. Powers describes a conglomerate in basal Atoka near Stapp containing rounded boulders of black chert and Ordovician limestone, tightly cemented in a sandy matrix. They measure up to 4 or 6 inches; the largest are a foot long.[1] Similar boulder beds occur in basal Atoka near Compton (T. 4 N., R. 22 E.). Miser[2] and Tomlinson[3] also mention Wapanucka-horizon conglomerates.

Perusing the literature, however, it strikes one that the stratigraphic correlations of these exposures seem still unsatisfactory as to what is Jackfork, Atoka, or Wapanucka, and that the structural relations of these strata are not clearly determined. In any case, it seems that there occur conglomerates, containing no great blocks, in horizons that are regarded as of Wapanucka age, and these lie to the northwest of the exposures of Johns Valley shale. These also contain Ordovician limestones, seemingly therefore Arbuckle-facies rocks. They seem to occur only in the immediate vicinity of the edge of the nappe, not far from the boulder-bearing Johns Valley shale outcrops, and not farther out in the foreland, nor in Arkansas. They appear, therefore, to be related either to the overthrust front or to the more interior zones of the autochtone.

We may, therefore, summarize the description of the Ouachita exotics as follows. They only occur in the Ouachita Flysch of Oklahoma, but not in Arkansas. The large blocks are confined to a relatively thin layer of not infrequently, but not always, mylonitized black shale of Upper Mississippian age, intercalated between the sandstones and shales of the Atoka and the massive Jackfork sandstone, the latter several thousand feet thick. The occurrence seems confined to this association in a zone of about 100 miles long, exclusively within the frontal zone of the overthrust sheets. The exotics constitute a practically complete assemblage of the sedimentary

[1] Sidney Powers, *op. cit.*, p. 1041.

[2] H. D. Miser and C. W. Honess, *op. cit.*

[3] C. W. Tomlinson, "The Pennsylvanian System in the Ardmore Basin," *Okla. Geol. Surv. Bull. 46* (1929).

rocks of the Arbuckle-Wichita sequence, in fragments up to the size of a large building. These rocks are completely foreign to the sequence of formations represented in the Ouachita Mountains, but they must be assumed to occur in the autochtonous basement buried beneath the thrust masses.

ORIGIN AND GENESIS OF THE OUACHITA EXOTICS

All geologists (Ulrich, Miser, Tomlinson, Powers, Woodworth, Taff) who have discussed these "boulders" seem to have come to the conclusion that these blocks are sedimentary, and must have been carried from outcrops in the Arbuckle province by floating ice or icebergs, and that they were dropped on the sea bottom in uppermost Mississippian or earliest Pennsylvanian time. Ulrich has expressed the conclusion again and again that they must have been deposited at the same time as the matrix enclosing them. He believes that the ice came from the Arbuckle Mountains. Tomlinson, Powers, and Miser think that the source was in some region east or southeast of the Arbuckles or adjacent ranges, from a location now buried beneath the Gulf Coast Plain, or under some of the present overthrusts of the Ouachita Mountains which had not yet come into existence at the time the matrix was deposited. That many of the boulders appear scratched or gouged has been adduced as evidence of their glacial origin. Ulrich gives some good photographs of scratched fragments,[1] but he comes to the conclusion that "it appears physically impossible that these phenomena can have been produced as slickensiding by movements in place or in a fault breccia. Neither could they have been made by the steady flowage of glacial ice." He believes, however, that they could be explained if boulders of varying hardness were imbedded in the base of floating masses of shore ice. A study of Ulrich's photographs, and of Caney boulders which the writer has personally examined, convinces him that these quite irregular scratches and deep short gouges are anything but glacial. He refers to a paper by K. Krejci-Graf[2] dealing with the many erroneous conclusions based on supposedly glacial scratches on boulders.

[1] *Op. cit.*, pp. 39–45.

[2] "Zur Kritik der Vereisungs-Anzeichen," *Senckenbergiana*, Frankfurt a/M., Bd. IX (1927), pp. 157–69.

The writer has further objections to a glacial or floating shore-ice theory for the old Carboniferous erratics in this region. They are the following:

1. Who has ever seen or heard of blocks of such enormous size (up to several hundred feet across) transported by floating ice, even of the magnitude of antarctic icebergs? Their size far exceeds that of any ice-borne rocks known. The only glacial erratics approaching such dimensions are sheared-off pieces of the substratum over which a very large glacier or land ice moved; and similar masses were never transported very far, and are always associated with extensive basal moraine deposits and occasionally with scratched rock floors.

2. The faunal and floral character of the Mississippian and Lower Pennsylvanian of the Ouachita and Arbuckle provinces certainly does not suggest glacial climatic conditions. The writer refers to the paleontological lists given by Ulrich, Miser, and Honess.[1] These are self-explanatory, even if we recognize fully that our conclusions as to climatic conditions under which Paleozoic organisms may have lived, must be drawn cautiously.

3. If these blocks had been transported by ice, or any other floating agency, where should they have come from to be deposited as a sedimentary product in a Mississippian shale? They comprise the whole sequence of pre-Pennsylvanian Paleozoics of the Arbuckle province. Granted that the Johns Valley shale ("Caney") of these Ouachita thrust sheets was deposited long before the major overthrusting of these mountains, it requires a Mississippian folding in the Arbuckle province of sufficient magnitude to create outcrops of this complete sequence, of an aggregate thickness of 15,000 feet, within a comparatively restricted area, from which these boulders could have reached the equally restricted area within which we now find them in this Ouachita "Caney." And even assuming that such an orogeny had taken place, how came the Morrow boulders in this Mississippian shale? This is Ulrich's difficulty and the cause of his controversy with Miser regarding the age of the Ouachita "Caney." However, there is no evidence of serious folding in the Arbuckle

[1] H. D. Miser, *op. cit.;* E. O. Ulrich, *op. cit.*; C. W. Honess, "Geology of Atoka, Pushmataha, McCurtain, Bryan and Choctaw Counties, Oklahoma," *Okla. Geol. Surv. Bull. 40-R* (1927).

Mountains and the Ardmore Basin before late Pennsylvanian. The earliest indicated intense folding in the frontal Wichita system, south of the Arbuckle Mountains, is post-Morrow. We must look to the central Red River folds before encountering any remote possibility of an orogenic phase that could have folded any Arbuckle-facies rocks and uplifted them sufficiently to enable late Mississippian erosion to cut deep enough into the folds to bare a considerable expanse of strata far down in the Cambro-Ordovician.

In the writer's opinion, these boulders and blocks are not glacial, and, at least in the case of the large blocks, not sedimentary. He believes that they are tectonic blocks, similar to such as we find in the frontal thrust sheets of many other mountain chains with a nappe structure.

In the mountain ranges of Europe exotic blocks of an entirely similar nature are well known. They have attracted attention and were described as early as the beginning of the nineteenth century. We know them from the entire Flysch front of the Alpine chains, from the Carpathians, the Apennines, and the Caucasus. They will no doubt be found in many other similarly built mountains. The extensive literature, however, occupies itself mostly with Alpine localities. The reader can be referred to treatises by Arnold Heim,[1] G. Geyer,[2] and H. P. Cornelius.[3] The two last-named papers contain an extensive bibliography on the subject.

The origin of the very large blocks among these exotics has always been puzzling; the problem is complicated by considerable confusion, since there exist many different kinds of these boulder beds and breccias which are by no means of the same origin. It resounds to the credit of Arnold Heim to have brought order out of the confusion.

There are three kinds of boulders, blocks, and gigantic masses in the Alpine Flysch zone, as distinguished by Heim: (1) Blocks belong-

[1] "Zur Frage der exotischen Blöcke im Flysch," *Eclogae geologicae Helvetiae*, 1907, pp. 413–24.

[2] "Über die Granitklippe mit dem Leopold von Buch Denkmal im Pechgraben bei Weyer," *Verhandlungen der geologischen Reichsanstalt* (Wien, 1906), pp. 363–90. (With extensive bibliography.)

[3] "Zum Problem der exotischen Blöcke und Gerölle im Flysch der Allgäu," *Jahrbuch der geologischen Bundesanstalt* (Wien, 1924), p. 229.

ing to the sedimentary sequence in which they are now found, originating from harder ledges in the same formation, which have been broken, rolled out, scattered, and displaced over more or less greater distances (*einheimische Flyschblöcke*). (2) *Klippen*, which are larger or smaller remnants of higher nappes, which have been bodily eroded; larger or smaller remnants now resting as exotics on entirely different strata. The Mythen peaks of Switzerland[1] are a classic example. We also know similar *Klippen* from the front zone of the northern Rocky Mountains, such as Chief Mountain, Montana, and Heart Mountain, Wyoming. Often these are huge masses, which could not be confused with erratic blocks; but not infrequently, small remnants have become much broken and scattered, and now appear as exotic blocks strewn over the surface. We could even imagine that such blocks were afterward covered by new sediment, and would appear as incorporated in such a layer. (3) True "exotic blocks": foreign rocks imbedded in the Alpine Flysch, notably in the Wildflysch, or other similar orogenic formations. They are larger or smaller boulders and blocks of rocks, which form no part of the sequence in which they are now enclosed but have been derived from some foreign series. They range in size from ordinary coarse breccias to blocks several hundred feet across. In the Alpine Flysch they happen to be predominantly crystalline rocks, though sedimentaries also occur. This is accidental.

These truly exotic blocks can again be subdivided in two kinds:

a)Blocks which have been enclosed in the matrix in which they are now found by *processes of sedimentation*. These boulder beds may be fans of ancient torrents (or could even be old glacial moraines in suitable localities); on ancient coasts they may have been caused by the action of the surf on beach cliffs. If climatic conditions would permit such an interpretation, there would be no objection to regarding some of the boulder beds as the result of floating ice derived from coastal or piedmont glaciers. Notably the very large blocks of this class may have been deposited at the base of former cliffs, from which they were dislocated by landslides and transported farther by mudstreams. In this case the interpretation postulates a considerable erosional break in the sedimentation, in conjunction with topo-

[1] L. W. Collet, *The Structure of the Alps* (London, 1927), pp. 264–66.

graphic relief of sufficient magnitude to expose the formations represented in the exotic blocks.

Examples of blocks of this class exist in the Cretaceous Gosau formation of the eastern Alps,[1] and also in the blocks in the Miocene of eastern Styria, in the Radelgebirge.[2] In both cases these are blocks which can be shown to have been derived from steep slopes in an ancient relief. Several of the large Flysch blocks may have originated in the same manner. It is evident that at the present time such blocks need no longer lay at a lower elevation than the place of their origin, but that, through subsequent tilting, folding, or even overthrusting, their present location may seem at a higher altitude than their source. This is, for instance, evidently the case in the Radelgebirge.[3] These Radel-blocks had also been explained as glacial before their true origin was recognized. The original source of such blocks in other localities may have been so displaced and obscured by subsequent structure as to have become utterly unrecognizable. If the block-bearing formation became later embodied in a thrust sheet, the boulder beds may now occur very far from the source region. An instance in which the genesis can be clearly traced is probably rather exceptional.

b)Another kind of exotics, finally, are blocks which have been sheared off from their original outcrops, or otherwise picked up, and are now tectonically embodied in other structural elements. These are, in part, what Ampferer has very adequately called "tectonic moraines." They occur notably at the base (in the "sole") of overthrust masses, sheared off from the autochtone substratum, particularly when the thrust was pushed over a surface showing a previous topographic relief. They were sheared off from ridges, rolled, worn, slickensided, gouged, and carried along in the thrust plane. Many

[1] O. Ampferer and Th. Ohnesorge, "Über exotische Gerölle in der Gosau und verwandten Ablagerungen der tirolischen Nordalpen," *Jahrbuch der geologischen Reichsanstalt, 1909* (Wien); O. Ampferer, "Beiträge zur Auflösung der Mechanik der Alpen," *Jahrbuch der geologischen Bundesanstalt, 1924* (Wien), pp. 35–73; *idem*, "Die Reliefüberschiebung des Karwendelgebirges," *ibid., 1928*, pp. 241–46; *idem*, "Einige Beispiele von Kerbwirkung und Reliefüberschiebung aus den süd-tiroler Dolomiten," *ibid., 1929*, pp. 241–56.

[2] A. Winkler, "Der Bau des Radelgebirges in Südwest-Steiermark," *ibid.*

[3] *Ibid.*, Figs. 4 and 5, p. 525.

of the larger and smaller exotic blocks of the Alpine or Carpathian Flysch front, imbedded in much crushed and macerated shaly beds, apparently belong to this class. These are confined to certain quite restricted zones and belts. This is easily understood, because they can only be present tectonically "downstream" relative to the motion of the overriding mass, scattering a certain ridge. It is not necessary that all such material is a breccia, actually pried loose from the solid outcrops by the overthrusting. If an old surface was covered by wash containing larger and smaller blocks of loose rock, more or less water-worn or corroded, these would likewise become embodied in the overriding mass. The effect of a thrust sheet on its substratum and the mechanics of such process are very similar to what happens under a large glacier, only on a much magnified scale. This fact was demonstrated by Ampferer from numerous sections studied in detail in the eastern Alps.[1] Ampferer called these overthrusts over a more or less differentiated topography: *Relief-Überschiebungen*.[2]

It is clear that, as the thrust masses move along, breaking up into smaller slices which slide and pile upon each other, or even become involuted, the original basal plane, carrying the exotic block picked up from the substratum, may finally become intercalated between quite different elements in such a complicated manner that it becomes next to impossible to unravel the sequence of events and trace the origin of the erratics unless exceptionally well-exposed detailed sections are available, as is sometimes the case in the high Alps but can scarcely ever be expected in less sharply dissected mountains. Thus, in Europe as well as in America, the majority of these orogenic exotics remain a grave problem. In many cases they have every appearance of having been deposited in the beds which now contain them by a process of sedimentation, though it remains difficult to devise a plausible explanation for the transportation of such huge blocks over any considerable distance. The hypothesis of drifting ice has also been repeatedly used in Europe,[3] though it

[1] *Op. cit.*

[2] Bailey Willis also believes that some of the Appalachian thrusts overrode an older relief: "erosion-thrusts."

[3] G. Geyer, *op. cit.*, p. 380; also A. Favre, H. Schardt, E. Renevier, Ch. Sarasin, Arnold Heim, Cornelius, and others.

remains inexplicable how the required extremely heavy ice could have occurred in the Cretaceous and Eocene seas of the Alpine region, associated with the prevailing fauna and flora, an assemblage which is much easier to collate with climatic conditions than is the case for Paleozoic forms. This assemblage does not suggest an even remotely appropriate climate. Even the well-known and often-cited conditions on the southwestern coast of Chili (known to the writer from personal observation) would not by any means be sufficient, and, moreover, could not possibly occur in a mediterranean sea as the Mesozoic Tethys, in a period when, generally, the world's climate was apparently considerably milder than in the present era.

The most conspicuous blocks of this nature in the Flysch front of the Alps have been more plausibly explained by the assumption of old ridges in the substratum of the overthrust masses. This is the case in the Carpathians as well as in the Alps. In part these overridden ridges are hypothetical, but not completely so, since both for the Alps and the Carpathians a few outcrops have been discovered which are generally (though not unanimously) considered as autochtone rocks, and would constitute actual bared portions of such ancient ridges.[1] This is notably the case, for the famous block bed in the Eocene Flysch of the Bolgenberg is the Allgäu Alps, on the border of western Austria and Bavaria.[2]

These ridges, mostly of crystalline rocks, have been named by C. Gümbel the "Vindelician chain," which is supposed to be traceable from the western Alps as far east as the east-Carpathian front. This ridge would, to a certain extent, mark the northern shoreline of the earlier Alpide geosyncline in late Mesozoic and early Tertiary time, since overriden by the thrust masses. In this conception there would be a marked parallelism between this Vindelician ridge and such uplifts as the Arbuckle Mountains of the American Mid-continent!

Only a careful study, not only of the exotic blocks themselves and their matrix, but of the structure of the entire region, may decide whether certain blocks in a certain location should be explained as sedimentary or as a purely tectonic product. In many cases the known facts do not yet permit a definite conclusion for many of the exotic Alpine Flysch blocks. The fact, however, that conspicuously

[1] *Ibid.*, pp. 373, 376, 382. [2] H. P. Cornelius, *op. cit.*

large and even unwieldy exotics of this nature are always so typically associated with the frontal zones of large nappes in overthrust mountain chairs suggests that in very many cases it must be this particular kind of structure that causes them. We cannot yet, indeed, explain the mechanics in detail, and still less trace the exact track of the majority of these swarms of exotic fragments. But it appears to the writer that the explanation must be sought in this direction. Most of such aggregates which contain very large blocks, and particularly those for which no nearby source region can be conceived, are very difficult to understand as having been placed where we now find them by any sedimentary means, but only by tectonic procedure. They must be blocks taken up from the autochtonous substratum by overriding thrust masses; they were carried along in shear planes and somehow incorporated, notably in softer crushed layers between more competent beds, which have acted as a gliding plane for masses moving relatively to each other. Ampferer has described in detail the mechanics of complex thrust masses moving over an autochtone relief, and how secondary shear planes are formed within the sheet through the obstruction caused by obstacles in the substratum.[1] Entirely similar phenomena can be seen to happen on a miniature scale in moving glacier ice.

It appears to the writer that in the frontal zone of the Ouachita Mountains and the location where the "Caney" boulders are found the very conditions are present for the occurrence of tectonic exotics.

We have a structure composed of thrust sheets which, by their totally different facies, postulate lateral displacement over considerable distances. We have great competent masses of sandstone (containing the 4,000–7,000-foot Jackfork member) and intercalated incompetent shales. In the autochtone substratum the presence of the various rocks of the Paleozoic Arbuckle series must be assumed for numerous reasons.[2] This substratum has been intensely folded and elevated by at least two major orogenic phases—the Wichita (early Pennsylvanian) and the Arbuckle (late Pennsylvanian) diastrophisms. The last of these does not antedate the final overthrusting

[1] "Beiträge zur Auflösung der Mechanik der Alpen," *op. cit.*

[2] W. A. J. M. van der Gracht, "Permo-Carboniferous Orogeny in South-Central United States," *op. cit.*

of the Ouachitas so far that considerable relief may not have persisted at the time when the Ouachita thrust sheets advanced over what may have been an old topography, as the Alpine thrust sheets did when they overrode an old relief. Consequently, very similar phenomena may have occurred as are so well in evidence at numerous localities in the European Alpides.

When, therefore, we find the entire Paleozoic sequence of the autochtone substratum represented in boulders and huge blocks in a comparatively thin layer of shale, locally traversed by mylonitized zones, at the base of several thousand feet of Atoka Molasse, and resting immediately on some 6,000 feet of Jackfork sandstone belonging to the Flysch sequence in the outer front of the Ouachita thrust sheets, it seems that the conclusion should be that these blocks are not only true exotics but should be considered a tectonic product.

The boulder-bearing streaks in this Johns Valley ("Caney") shale are probably no "beds" at all, and much of the shale may be a mass of out-rolled Upper Mississippian shale (which normally may have been very much thicker), over which the overlying mass of Atoka Molasse has glided relatively to the underlying Jackfork; in other words, the contact is possibly only tectonic.

This explanation would do away with the difficulty that early Pennsylvanian Morrow boulders are imbedded in a shale which, judging from fossils, must once have been an Upper Mississippian sediment. The overthrusting occurred later: this is the main requisite.

We must, however, point to some puzzling facts which remain difficult to explain. Some of the shale enclosing the boulders does not appear mylonitized or crushed. In a not much indurated shale this is not always easy to determine with certitude, and a large shear plane frequently contains numerous slices of undeformed rock.

No granite or other basement rocks occur among these exotic blocks, although after the Arbuckle orogenic phase, the pre-Cambrian had become considerably bared on the ridges by erosion. The final phase of the overthrusting of the Ouachita nappes must have been after the Arbuckle orogeny. It is possible, however, that the special ridge which yielded the exotics occurring in this restricted area may have contained no exposed pre-Cambrian.

SUMMARY

The writer's conclusion is, therefore, that the "Caney" boulders of the Ouachita Mountains in Oklahoma are by no means glacial; that, very probably, these very large blocks are not even sedimentary, but exotic, blocks of a purely tectonic origin, a true "tectonic moraine" in the sense of Ampferer, displaced a considerable distance toward the north.

Some of the fragments may have been pried loose from solid outcrops; others may have been in an ancient surface wash, and been picked up by the overriding thrust mass, weathered and corroded before this happened.

The source is from ridges in the buried southeastern prolongation of the Arbuckles or more southernly chains of the Wichita system, which antedated the final overthrusting of the Ouachita Mountains. Elements of the nappes, gliding over each other, have carried these fragments along in an intervening shear plane. When a some 15,000-foot thick thrust mass, consisting of massive sandstone members separated by shale beds, moved over a more or less rough relief, it is self-evident that the sandstones must have become displaced relative to each other, with shale beds as lubricants. Probably the entire mass broke up in an infinite number of minor thrust slices, and it is therefore hopeless to attempt to trace the track of these boulders through this probably very complicated maze of shear planes. Without extremely detailed mapping (provided the outcrops permit such), any attempt of this kind would be worthless speculation.

Before the structure is known in minute detail, it will also be impossible to decide definitely whether these exotics are exclusively of tectonic origin or whether they may all or in part have been derived from exposed ridges by sedimentary processes, as has been described.[1] Even in the latter case, they would have been carried a long distance north of their place of origin by the overthrusting, and probably would have become associated with strata in no way connected with their original environment. It would remain very difficult to picture the origin of such Wichita ridges in pre-Morrow time which could yield blocks to a Flysch deposit by sedimentary processes. If blocks of the not yet existing Morrow are included in the boulder beds, it becomes obviously an impossibility.

[1] P. 708.

SPONTANEOUS ROCK EXPANSION

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ABSTRACT

Quarrying in Vermont and Tennessee shows spontaneous expansion of marble as new surface is produced. Measurements in Vermont show an elastic expansion and a prolonged or hysteresis expansion. Compression of the marble is believed to have occurred when the rocks were folded during the Taconic disturbance.

Marble has broken violently during quarrying, without application of strain by quarrying machinery, in the abandoned quarries at South Wallingford, Vermont, in the Florentine Blue quarry, the Valley quarry, Florence quarries No. 5 and No. 6, and Pittsford Valley quarries No. 3 and No. 6 in Pittsford, Vermont. The Valley quarry was abandoned because bursting was so violent. Only great care in placing channel cuts and speed of cutting them saved any stock from the Florentine Blue quarry. Cutting the west wall first in the Pittsford Valley quarries, so as to free the part of the stone to be saved from the main body, resulted in recovery of most of the stock. Recently not even this precaution has sufficed in the deeper parts of Pittsford Valley quarry No. 6.

HISTORY OF EXPANSION OBSERVATIONS

Men who operated the South Wallingford quarries reported that the stone frequently closed in on the drill steel while work was in progress. Attempts to use diamond borers were unsuccessful because the stone closed in on the tools and prevented rotation.

The Valley quarry was opened on the eastern or lower Columbian deposit. The rock surface is relatively flat or gently rolling; deep rock gorges, so common through much of the marble belt, are entirely lacking. The stone began to burst violently at a depth of about 25 feet, and the ruptures in the floor occurred with such force that channeling machines weighing over one ton were thrown from their tracks.

The Florentine Blue quarry was opened on a dark-blue marble zone lying almost immediately below the Hudson River slate.

Bed rock rises about 60 feet on its western side, and the overburden is about 30 feet deep on the eastern. Solution caverns occur in the southeastern part, but otherwise the rock surface is essentially horizontal. Good stock was produced for a period, especially from the upper part of the middle opening just north of the solution caverns. Then, like the Valley quarry, bursting became a daily event. This trouble has been avoided to a certain extent by first cutting the channel farthest removed from an existing quarry face; the bottom holes for raising the floor are drilled next, and the side walls of a strip of marble are cut simultaneously. Work cannot stop until an entire strip is free, otherwise a diagonal fracture rises from the bottom western part of the strip to the top eastern part.

The Pittsford Valley quarries are opened on layers lying between the Riverside and Brandon Italian deposits of the lower Columbian zone. The same marble occurs in the Florence quarries No. 5 and No. 6 at the south end of the Pittsford Valley deposit. A deep mud-filled gorge of great, but unknown, depth lies east of the north end of the openings and very close to them, but does not extend to great depth south of Pittsford Valley quarry No. 6. A hill rises 120 feet above and west of the quarries. Pittsford Valley quarry No. 4 and occasionally those north of it began to give some trouble from spontaneous expansion when the thickness of rock beyond the east wall (between the quarry and the mud-filled gorge) exceeded 40 feet. However, the trouble was not serious and was easily overcome by cutting the west wall first. The same trouble was encountered in quarry No. 6 but at shallower depth; and at the present level, where the east wall is 93 feet thick, cutting the west wall first is not a sure remedy, and the last floor quarried developed a number of fissures by expansion.

Florence quarries No. 5 and No. 6 lie east of a shallow mud-filled valley that runs diagonally across the deposit just south of Pittsford Valley No. 6. Good stock, but in thin layers, was quarried from the surface down to 50 feet; below this level bursting was violent and every block developed gaping cracks.

EVIDENCE OF STRESS DIRECTION

Experiment at the Florentine Blue and Pittsford Valley quarries indicated that placing first channel cuts or drill holes farthest from

the bed-rock surface, or even a free surface, gave the greatest saving of stone. The flat contour of the rock made removing of stone in this way impractical at the Valley quarry.

The strain which culminates in fissuring, or "bursting" as it is called, appears to have been relieved adjacent to the present rock floor, as evidenced by absence of expansion and bursting in the upper 20 feet of any quarry. It seems to be relieved also near quarry faces already in existence, but for lesser distances than from original rock surfaces. Placing a cut at a long distance from an old opening or keyway in the Florentine Blue quarry allowed the stone to close in on the channel steel and eventually produce bursting of the marble. Time during which a free surface of relief has existed seems to be an important factor in determining the width of the relieved zone.

Closing of channel cuts in Pittsford indicates either that the walls of the quarry are closing in as the stone is removed or that the marble itself is increasing in volume when space is provided into which it may expand. Pillars in Pittsford Valley quarry No. 6 are nearly vertical, but incline to the east, and are about 30 feet apart; channel cuts around them are placed, one parallel to the original rock surface of the mud-filled gorge immediately to the east and the other at right angles thereto. The gauge of the steel used indicates that the top of each channel closes from approximately 1½ inches when the cut is started to about 1 inch when it is bottomed. This indicates that the change is not linear but probably volumetric.

RECENT EVIDENCE OF NATURE OF STRESS

Strip rupture.—Strains in the last floor quarried in Pittsford Valley quarry No. 6 caused fissures to open most frequently near the channel cut at the west side of the quarry and at the bottom or slightly below the bottom of it; less often the rupture started in the middle of the strip. The fissures curve upward from the west wall and downward to the east wall, usually rising toward the back of the strip. (Fig. 1). The center of a fissure is almost invariably open, and in cases the opening was ½ inch wide, but the ends were always closed.

Walls of the channel being cut close in at the time the fissure develops. This type of fissure lacks bottom support and could be de-

FIG. 1.—Photograph of a strip burst. Observe the arch form of the fissures. The lower fissure does not intersect a channel; the upper one does. Notice how the burst not intersecting a channel or free surface is open in the middle but closes at the ends.

veloped only by lateral pressure causing an arching effect. This force might be developed by the walls of the quarry crushing into the open space. However, it is almost inconceivable that any pressure could be transmitted through the open channel cut. The pressure causing the arch effect could be developed equally well as a reaction force to an internal force developed by internal expansion of the marble against the fixed east wall and the bottom which is firmly fixed up to the time of rupture.

Wall rupture.—Wall and pillar rupture is more frequent than strip rupture. Furthermore, the west wall, which is beyond the relieved

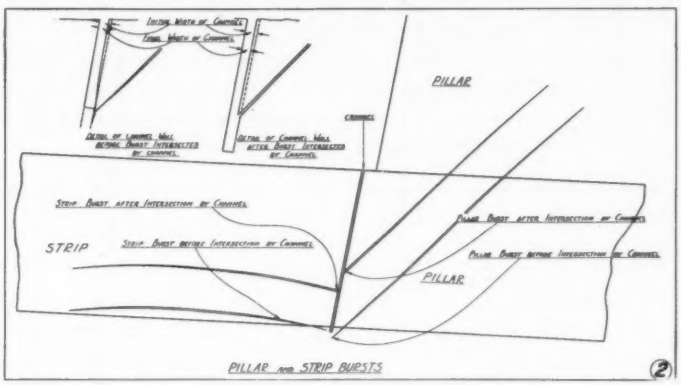

FIG. 2.—Diagram showing closed ends of pillar bursts before intersection by a channel, and the sprung ends after intersection.

zone adjacent to the bed-rock surface, ruptures more and more often than the east wall which is adjacent to it. The fissures are at about 45° to the horizontal and closely resemble, in direction, breaks produced by crushing of a column; their form differs by being very open adjacent to the channel cut and closing up gradually at greater distance into the wall (Fig. 2). Crush ruptures developed by dead vertical load are closed throughout.

No fractures observed to start immediately after a channel was cut, or while it was being cut, appeared to be due to exterior forces applied through the quarry walls. Under these stresses the marble should show no change or slight contraction. Strain produced by development of a reaction force due to volume increase would be

evidenced by expansion of measurable lengths of marble in a strip, and decrease in width of the channel cut should be approximately equal to twice the rock expansion if closing of the cut is due to this cause. Half the closing of the cut would be due to expansion in the strip and half to expansion in the wall.

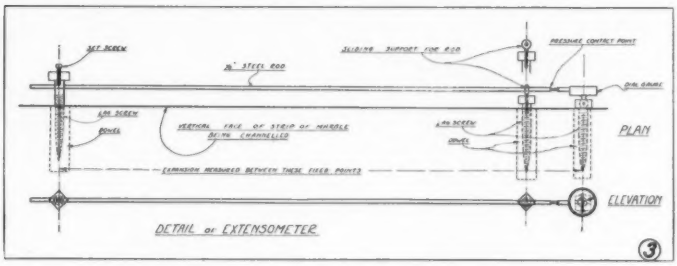

FIG. 3.—Design of extensometer used in measurements

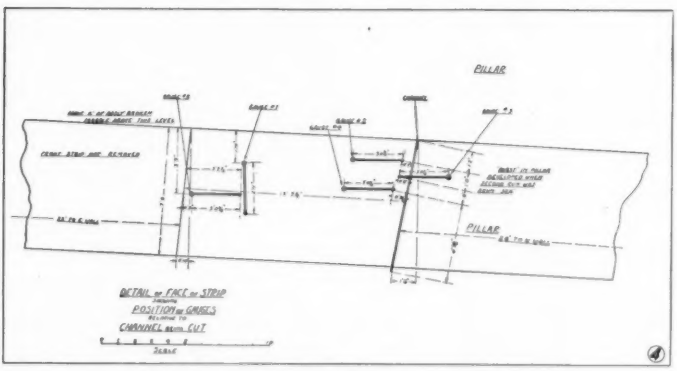

FIG. 4.—Location of gauges relative to channel being cut

TESTS APPLIED

Extensometer gauges of the design shown in Figure 3 were attached to a strip in Pittsford Valley quarry No. 6, as shown in Figure 4; one gauge was placed across the cut. Dial types of gauges measuring to .001 inch, and estimating to .0001 inch, were used. The distance chosen to be gauged for change of length was as near 3 feet as

TABLE I

Day and Time	Gauge				Depth of Channel (Inches)	Remarks
	No. 1	No. 2	No. 3	No. 4		
11/9/30						
9:40	0	0	0	0	21	
9:45	98.5	− 1.1	1.1	0		
9:47	98.1	− 1.6	2.5	0.2		
9:51	98.0	− 2.3	3.6	0.5		
9:53	97.9	− 3.3	4.6	0.5		
9:54	97.9	− 3.4	5.3	0.5		Work stopped
9:59	97.8	− 3.5	5.4	0.5	26	Work resumed
10:03	97.8	− 4.0	6.8	0.5		
10:05	97.6	− 4.2	7.7	0.7		
10:08	97.6	− 4.5	8.7	0.6		Work stopped
10:10	97.6	− 4.7	9.6	.....		
10:11	.....	.....	.....	.....		Work resumed
10:13	97.6	− 5.0	10.8	0.3		
10:16	97.6	− 5.4	12.3	0.1	30	
10:21	97.5	− 6.0	15.0	99.8		
10:24	97.4	− 6.5	16.8	99.2		
10:26	97.3	− 6.8	18.2	99.0		
10:29	97.3	− 6.9	18.6	98.9		
10:31	97.2	− 7.0	19.5	98.9		Work stopped
10:35	97.2	− 7.0	19.5	98.9		Work resumed
10:37	97.2	− 7.3	21.0	98.2	34	
10:40	97.2	− 7.5	22.8	97.8		
10:42	97.2	− 7.6	23.6	97.2		Work stopped
10:49	97.2	− 7.7	23.5	97.5		
11:07	97.2	− 7.8	23.5	97.5		Change steel
11:28	98.5	− 8.0	23.5	97.5		
11:30	98.5	− 8.0	23.5	97.5		
11:35	98.1	− 8.0	23.8	97.5		Work resumed
11:38	98.1	− 8.0	24.6	97.2	36	
11:41	98.1	− 8.2	26.0	96.9		
11:44	98.0	− 8.5	28.3	95.9	38	
11:47	98.0	− 8.5	29.2	95.2		
11:50	98.0	− 8.9	30.8	94.5	39¼	
11:53	98.0	− 9.0	33.2	93.2		
11:55	98.0	− 9.2	33.5	93.0		Work stopped
12:33	98.0	− 9.5	33.5	93.0		
12:35	.....	.....	.....	.....		Work resumed
12:37	98.0	− 9.6	34.5	92.7		
12:40	98.0	− 9.7	35.5	92.1	41½	
12:44	98.0	− 9.9	37.4	91.3		
12:47	98.0	−10.0	38.5	90.9	43½	
12:49	98.0	−10.2	40.0	90.0		
12:53	98.0	−10.3	42.4	89.0	46	
12:55	98.0	−10.5	43.0	88.5		
12:59	98.0	−10.6	45.2	88.0	48½	
1:02	98.0	−10.7	46.6	87.3		
1:05	98.0	−11.0	48.4	87.0	50	
1:08	98.0	−11.0	49.5	86.2	51½	
1:12	98.0	−11.2	51.3	86.0		
1:14	98.0	−11.2	52.1	85.7	52½	
1:17	98.0	−11.3	53.5	85.2	53¾	

TABLE I—*Continued*

Day and Time	Gauge				Depth of Channel (Inches)	Remarks
	No. 1	No. 2	No. 3	No. 4		
1:20	98.1	−11.4	54.5	85.0		
1:23	98.2	−11.6	55.4	84.9	55½	Work stopped
1:26	98.3	−11.7	55.5	84.6		
1:30	98.2	−11.7	55.6	84.6		
1:40	98.2	−11.7	56.0	84.7		
1:46	98.2	−11.8	56.0	84.7		Work resumed at 1:49½
1:50	98.2	−11.8	56.4	84.5		
1:52	98.3	−11.9	57.2	84.2		
1:54	98.3	−12.0	58.0	84.0		
1:58	98.3	−12.0	59.4	83.9		
2:00	98.3	−12.1	60.5	83.7	59½	
2:04	98.3	−12.2	62.1	83.2		
2:06	98.3	−12.3	63.0	83.1	61½	
2:09	98.5	−12.4	63.9	83.0		
2:12	98.6	−12.5	65.0	82.8	64	
2:15	98.6	−12.6	65.9	82.6	65½	
2:18	98.6	−12.7	67.0	82.3		
2:21	98.6	−12.8	68.0	82.2	68	Work stopped
2:38	98.6	−13.0	68.2	82.1		
2:44	98.6	−13.0	68.4	82.0		Work resumed
2:47	98.6	−13.2	69.4	81.8		
2:50	98.6	−13.3	70.0	81.7	71	
2:53	98.6	−13.5	71.5	81.2	74	
2:55	98.7	−13.6	72.7	81.1		
2:58	98.7	−13.8	73.8	81.0	77	
3:01	98.7	−13.8	75.0	81.0		
3:04	98.7	−14.0	75.9	81.0	79½	
3:06	98.7	−14.0	76.1	81.0		Work stopped
3:17	98.7	−14.0	76.3	81.0		
3:25	98.7	−14.1	76.5	80.9		
12/9/30						
7:03	98.7	−15.4	78.5	80.6		Work resumed for ½ minute
7:15	98.7	−15.5	79.0	80.2		
7:25	.....	.....	.....	.....		Work resumed
7:27	98.7	−16.0	79.5	80.0	81½	
7:30	98.7	−16.1	79.7	80.0	83¾	
7:33	98.7	−16.2	80.0	80.0	86	
7:37	98.6	−16.2	80.0	80.0	88¾	
7:40	98.4	−16.3	81.0	80.0		
7:47	98.4	−16.3	81.3	80.0	92	Cut bottomed: 8 foot run at top, 2 foot run at base
8:00	98.4	−16.3	81.2	79.8		
8:15	98.4	−16.3	81.2	79.7		Started cut along prolongation of former one
8:24	98.4	−16.3	81.3	79.8		
8:41	98.4	−16.3	81.3	79.7		
8:45	98.4	−16.3	81.3	79.6		
8:58	98.4	−16.3	81.3	79.6		Many stops until 9:07
9:07	98.4	−16.3	81.4	79.6	6	
9:14	98.4	−16.3	81.5	79.6	9	
9:22	98.4	−16.4	81.6	79.3	11	
9:27	98.4	−16.3	81.9	79.5	14	

TABLE I—*Continued*

Day and Time	Gauge				Depth of Channel (Inches)	Remarks
	No. 1	No. 2	No. 3	No. 4		
9:33	.....	−16.3	82.1	79.5	15½	
9:34	.....	.....	.....	.....		Work stopped
9:46	98.4	−16.3	82.1	79.6		
10:02	98.6	−16.3	82.3	79.7		Work resumed
10:06	98.6	−16.3	82.8	79.6	16½	
10:10	98.6	−16.3	83.1	79.6	17½	
10:15	98.5	−16.3	83.2	79.6	18½	
10:20	98.6	−16.3	83.5	79.6	21	
10:27	98.6	−16.3	83.9	79.6	23	
10:32	98.5	−16.2	84.1	79.6	25	Work stopped
10:40	98.5	−16.2	84.1	79.7		
10:48	98.5	−16.3	84.1	79.6		Work resumed
10:52	98.5	−16.2	84.4	79.7	27½	
10:56	98.5	−16.2	84.7	79.7	29	
11:03	98.5	−16.2	85.0	79.8	31¼	
11:06	98.5	−16.2	85.2	79.8	34	Work stopped
11:18	98.5	−16.2	85.2	79.8		Work resumed
11:27	98.5	−16.2	86.0	79.8	37½	
11:33	98.6	−16.2	86.4	79.8	41	
11:39	98.6	−16.2	86.9	79.8	42	
11:41	98.5	−16.2	87.0	79.9	43¼	Work stopped
11:55	98.5	−16.2	87.0	79.9		
12:34	98.6	−16.2	87.1	79.8		
12:48	98.6	−16.2	87.2	79.8		Work resumed
12:58	.....	−16.1	88.0	79.8	47	
1:06	98.7	−16.1	119.0	80.4	50¼	Pillar "burst"

Gauge No. 2 discontinued and reset as gauge No. 5

Day and Time	Gauge				Depth of Channel (Inches)	Remarks
	No. 1	No. 3	No. 4	No. 5		
12/9/30						
1:32	98.7	161.2	80.0	0	57¼	
1:35	98.7	162.2	80.0	− 2.3	57¾	
1:38	98.7	162.8	80.0	− 3.0		
1:42	98.7	163.3	79.9	− 3.6	58½	
1:48	98.7	164.0	80.0	− 4.2	59½	
1:53	98.7	165.7	80.1	− 4.6	60½	
1:59	98.7	165.5	80.1	− 4.9	61¾	
2:04	98.7	167.5	80.1	− 5.1	62¼	
2:06	98.7	167.9	80.1	− 5.2	63½	Work stopped
2:16	98.7	169.0	80.1	− 5.4		
2:35	98.7	170.0	80.1	− 5.8	63¾	Work resumed at 2:34
2:43	98.7	171.0	80.1	− 6.0	65¾	
2:52	98.7	172.5	80.1	− 6.1	68¼	
2:58	98.7	173.5	80.1	− 6.2	69¼	
3:04	98.7	174.5	80.1	− 6.3	70	
3:09	98.7	175.1	80.1	− 6.4	71½	

TABLE I—*Continued*

Day and Time	Gauge				Depth of Channel (Inches)	Remarks
	No. 1	No. 3	No. 4	No. 5		
3:14	98.7	175.8	80.1	− 6.5	73½	
3:18	98.7	176.6	80.1	− 6.6	74½	
3:24	98.7	177.0	80.1	− 6.7	75¾	Work stopped
13/9/30						
8:00	98.8	180.6	80.1	− 8.9		
2:30	98.8	181.6	80.1	− 9.3		
6:10	98.8	182.0	80.1	− 9.6		
14/9/30						
9:30	98.8	182.5	80.1	−10.3		
2:00	98.8	182.7	79.9	10.45		
6:30	98.7	182.9	80.2	10.50		
15/9/30						
7:05	98.7	183.0	80.1	10.90		Started work at 7:08
7:15	.....	183.7	.....	10.90	76	
7:28	.....	183.8	.....	11.0	76¼	Work stopped
7:47	98.7	183.9	80.1	11.0		Work resumed
7:56	.....	184.4	80.1	11.0	78	
8:03	.....	184.8	.....	11.0	78½	
8:08	.....	185.2	.....	11.0	79¼	
8:15	98.7	185.7	80.2	11.05	81	
8:23	.....	186.6	.....	11.15	83	
8:27	98.7	187.2	80.15	11.25	84	
8:28	.....	.....	.....	.....		Work stopped
8:33	98.9	187.5	80.15	11.35	85	Resumed 8:30
8:41	.....	188.5	.....	11.50	86¼	Channel closed in
8:51	.....	188.8	.....	11.6		on steel most of
9:02	98.9	189.6	80.2	11.65	88	time. Machine
9:08	99.0	190.4	.....	11.7	89½	stuck periodical-
9:17	99.0	191.2	80.25	11.85	91	ly.
9:20	98.95	191.4	80.25	11.90		
9:25	98.95	191.4	80.25	11.90		
9:40	98.95	191.6	80.25	11.95		
9:49	98.95	191.6	80.30	11.9		Work resumed at 9:51
10:05	99.0	192.4	80.5	12.20		
10:15	.....	194.0	.....	12.2		
10:22	99.0	194.2	80.6	12.3	93	Work stopped
10:57	99.05	194.45	80.35	12.3		Work resumed -
11:00	.....	194.8	.....	12.35	94½	
11:12	99.05	195.3	80.3	12.5	96¼	
11:18	99.1	195.6	80.35	12.5		
11:24	99.1	196.6	80.35	12.6	97½	
11:30	99.1	197.25	80.35	12.7	100	
11:35	99.05	197.70	80.35	12.8	101¼	Cut bottomed
12:30	.....	198.5	.....	12.8		
2:00	.....	198.5	.....	12.9		New cut started
3:25	.....	198.7	.....	12.9	28½	along prolonga-
6:30	99.3	198.7	80.2	12.9		tion of channel

possible; greater lengths gave vibrations on the gauge rods, and lesser ones had too small total expansion. The gauge was screwed firmly into a dowel set in the marble; a rod was attached firmly to another dowel 3 feet away. The end of the rod pressed against the plunger of the dial indicator. Any lateral movement of the rod resulted in the plunger moving in or out and indicating the amount of movement on the dial.

The quarries are completely shut off from direct sunlight, and winter ice remains in them the year around. During midsummer water lies in small pools on and under the ice. Temperature, therefore, remains nearly constant and very close to 0° C., irrespective of surface temperature. Thermal corrections are unnecessary to obtain true rock expansion, and actual dial readings are given in Table I.

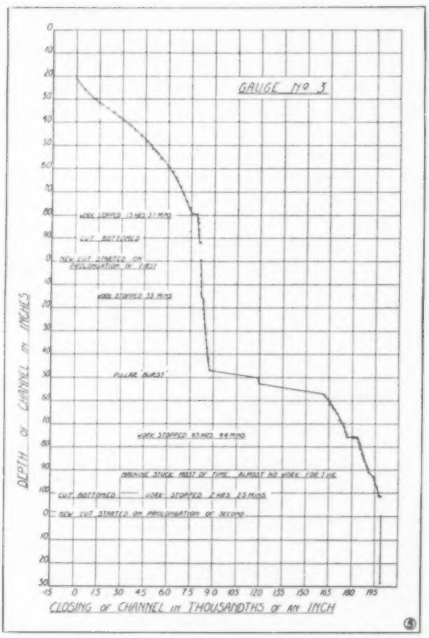
GAUGE NO 3
DEPTH OF CHANNEL in INCHES
CLOSING OF CHANNEL in THOUSANDTHS OF AN INCH
-15 0 15 30 45 60 75 90 105 120 135 150 165 180 195

FIG. 5.—Curve showing rate of closing of channel cut at level of gauge No. 3. Depth of channel, or amount of new surface produced, is plotted as ordinates and amount of closing as abscissas.

RESULTS OF THE MEASUREMENTS

Results of the measurements show very conclusively that the rock expands spontaneously. The expansion in the western part of the strip is approximately .020 inch in a length of 3 feet laterally. Gauge No. 1 shows that vertical expansion is negligible, although appreciable in the deposit as a whole as indicated by the stress directions in the Valley quarry and the Florentine Blue quar-

ries. It seems that strain in a vertical direction has been relieved completely when the overlying strip was pulled. The coefficient of lateral expansion, together with the number of open fissures attendant upon a wall's bursting completely, accounts for decrease in channel width.

General gauge readings.—Gauge No. 3 was placed across the channel cut and approximately $5\frac{1}{2}$ feet above the bottom of the cut (Fig. 5). Closing of the channel cut due to expansion of the marble in the strip and in the quarry wall proceeded regularly until it amounted to .088 inch. Assuming that the strip and the wall expanded equally, this represents .044 inch expansion on each side of the channel; .020 inch strip expansion occurred in the first 3 feet of the strip. The middle of gauge No. 5 was 12 feet from the channel cut. The curve for this gauge (Fig. 6) indicates that expansion did not begin until the third run on the channel reached a depth of 50 inches. Expansion not occurring in the first 3 feet of the strip amounting to .024 inch occurred before the third run reached a depth of 50 inches, and therefore must have occurred in the 7 feet intervening between gauge No. 4 and gauge No. 5. The entire expansion is very close to the channel cut.

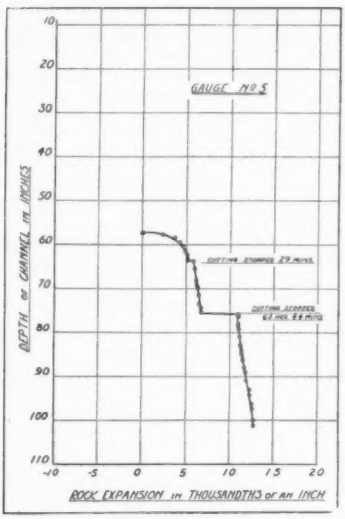

FIG. 6.—Expansion curve for gauge No. 5. Depth of channel is plotted as ordinates against expansion as abscissas.

INSTANTANEOUS EXPANSION OR ELASTIC RESPONSE

Rate of expansion.—Rate of expansion relative to the depth of cut, i.e., to the amount of free surface produced, is plotted on curves. These curves resemble deflection curves for cantilever beams and suggest that the deflecting stresses are due to disturbance of balanced tensile and compressional stresses in highly compressed rock

(Fig. 7). The channel cut removes the back compressive stress maintaining the balance and allows deflection until the strain builds up the tensile stress to balance it. Tensile stress is constant for the entire length of the cut, and therefore is equivalent to a positive load on a deflected cantilever beam. The compressive stress is due to the restraining force of the positive tensile stress, and at any point is directly proportional to the moment of the tensile stresses about any point along the channel cut; it is equivalent to a negative load on the beam.

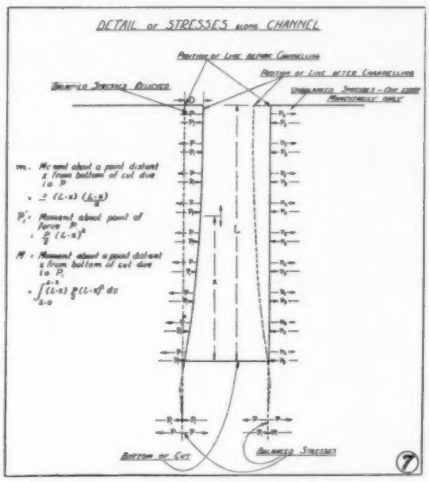

FIG. 7.—Diagram showing stresses in rock before and after the channel is cut.

Calculation of expansion.—The symbols used in the following calculations are as indicated in Figure 7. Those not given in Figure 7 are indicated below.

E = Young's modulus of elasticity
I = Moment of inertia of strained stone
y = Deflection due to positive load (decreasing expansion)
Y = Deflection due to negative load (causing expansion)
m = Moment due to positive load
M = Moment due to negative load

Elastic curve equation for positive load becomes:

$$EI\frac{d^2y}{dx^2}=m\,. \tag{1}$$

Elastic curve equation for negative load becomes:

$$EI\frac{d^2Y}{dX^2}=M\,. \tag{2}$$

The positive load bending moment about any point distant x from the fixed end is:

$$m = P(L-x)\frac{(L-x)}{2}$$

$$= \frac{P}{2}(L^2 - 2Lx + x^2). \tag{3}$$

The negative bending moment about any point distant x from the fixed end is:

$$M = \text{sum of bending moments about } x$$

$$= \int_{x=0}^{x=x} \underline{(L-x)}\ Y^*\, dx. \tag{4}$$

* Y as used here is merely the ordinate of the bending moment curve and is equal to $\frac{P}{2}X^2$ where X is the abscissa for the ordinate Y. X is equal to $L-x$ when used in equation (4).

Substituting these values, equation (4) becomes:

$$M = \int_{x=0}^{x=x} (L-x)\frac{P}{2}(L-x)^2 dx$$

$$= \int_{x=0}^{x=x} \frac{P}{2}(L-x)^3 dx$$

$$= \int_{x=0}^{x=x} \frac{P}{2}(L^3 - 3L^2x + 3Lx^2 - x^3) dx$$

$$= \frac{P}{2}\left(L^3x - \frac{3L^2x^2}{2} + \frac{3Lx^3}{3} - \frac{x^4}{4}\right). \tag{5}$$

Substituting in equations (1) and (2),

$$EI\frac{d^2y}{dx^2} = m = \frac{P}{2}(L^2 - 2Lx + x^2). \tag{6}$$

$$EI\frac{d^2Y}{dx^2} = M = \frac{P}{2}\left(L^3x - \frac{3L^2x^2}{2} + Lx^3 - x^4\right). \tag{7}$$

Integrating equation (6), it becomes:

$$EIy=\frac{P}{2}\left(\frac{L^2x^2}{2}-\frac{Lx^3}{3}+\frac{x^4}{12}\right)$$

$$=\frac{P}{240}\ (60\ L^2x^2-40Lx^3+10x^4)\ . \tag{8}$$

$$y=\frac{P}{240\ EI}\ (60L^2x^2-40Lx^3+10x^4)\ . \tag{9}$$

Integrating equation (7), it becomes:

$$EIY=\frac{P}{2}\left(\frac{L^3x^3}{6}-\frac{L^2x^4}{8}+\frac{Lx^5}{20}-\frac{x^6}{120}\right)$$

$$=\frac{P}{240}\ (20L^3x^3-15L^2x^4+6Lx^5-2x^6)\ . \tag{10}$$

$$Y=\frac{P}{240\ EI}\ (20L^3x^3-15L^2x^4+6Lx^5-2x^6)\ . \tag{11}$$

$$Y-y=\frac{P}{240\ EI}\ (20L^3x^3-15L^2x^4+6Lx^5-2x^6-60L^2x^2+40Lx^3-10x^4)\ . \tag{12}$$

This deflection is calculated on the assumption that the expansion $(Y-y)$ is offset by a contraction at some other point.[1] No such contraction takes place, but expansion is volumetric. Expansion is therefore divided four ways, one part to offset the contraction assumed to take place at right angles to the expansion designated by the elastic curve

$$EI\frac{d^2y}{dx^2}\ ,$$

and one part in each of the three space directions.

$D=$ Deflection (expansion of marble) $=\sqrt[4]{Y-y}$

$$=\sqrt[4]{\frac{P}{240\ EI}}\ (20L^3x^3-15L^2x^4+6Lx^5-2x^6-60L^2x^2+40Lx^3-10x^4)\ . \tag{13}$$

Let

$$\sqrt[4]{\frac{P}{240\ EI}}=K\ .$$

[1] The elastic curve assumes contraction of cross-section proportional to elongation. No contraction occurs; so the fourth root correction must be applied.

Then all values for equation (13) can be obtained from readings on gauges Nos. 2 and 4 except for K. This value can be calculated by substitution of the gauge readings in the equation. $L=5$ feet (deflection curve becomes asymptotic at 5 feet, and gauge shows no further expansion).

TABLE OF VALUES OF x AND K

x	D	K
0 feet	0	0
1 foot	0.00067 feet	12.45×10^{-5}
2 feet	0.00120 feet	12.00×10^{-5}
3 feet	0.00146 feet	10.78×10^{-5}
4 feet	0.00158 feet	9.62×10^{-5}
5 feet	0.00167 feet	8.94×10^{-5}

The quantity K evidently is not a constant. Values for K relative to x were plotted on a graph; it is evident that K is a linear function of X and may be represented by the following equation:

$$K=(13.4-0.88x)10^{-5}=\sqrt[4]{\frac{P}{240\,EI}}.$$

Cause of variation in K.—Observations on gauge Nos. 2, 4, and 5 showed that marble adjacent to the channel had expanded completely before the stone at gauge No. 5 began to undergo any change. Expansion is toward the free surface, and the amount of stone undergoing expansion increases as the amount of free surface is increased. Increase in amount of stone undergoing expansion causes increase in the moment of inertia I; however, as the part of the stone undergoing expansion is wedge-shaped, the moment of inertia decreases out of linear proportions as the bottom of the cut is approached. This behavior causes the value of K to increase beyond the calculated value unless the foregoing correction is applied.

The curve for elastic expansion of the marble may be represented by the following formula:

$$D=[(13.4-0.88x)10^{-5}]\sqrt[4]{20L^3x^3-15L^2x^4+6Lx^5-2x^6-60L^2x^2+40Lx^3-10x^4}.$$

This equation fits perfectly the observed expansion curve for gauge Nos. 2 and 4 (Figs. 8 and 9). Values for L and x could not be estimated for gauge No. 5; so that it was not possible to apply the gen-

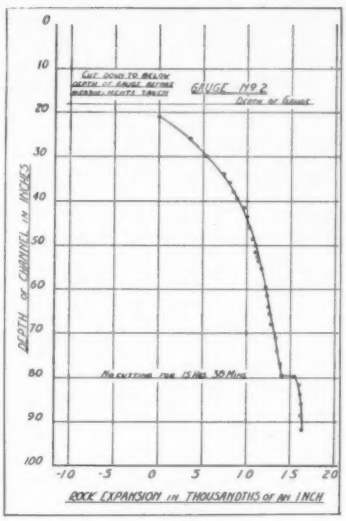

FIG. 8

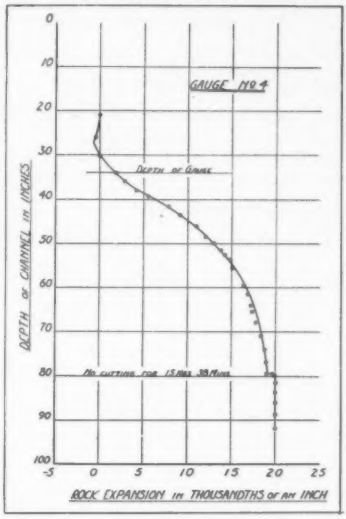

FIG. 9

FIG. 8.—Expansion curve for gauge No. 2. Depth of channel is plotted as ordinates against expansion as abscissas.

FIG. 9.—Expansion curve for gauge No. 4. Depth of channel is plotted as ordinates against expansion as abscissas.

eral formula to readings taken on it. Gauge No. 2 is located at approximately the same distance from the channel cut as gauge No. 4 and is 20 inches above the latter. The expansion curves for gauge No. 4 (Fig. 9) for a channel depth between 40 and 90 inches is the same as that for gauge No. 2 (Fig. 8) between 20 and 70 inches. Thus, for the two gauges, located at the same distance from the channel, the amount of expansion is directly proportional to the distance from the bottom of the channel cut.

SLOW CREEP

Expansion is almost instantaneous adjacent to the channel; nevertheless, a slow creep is evident. This slow creep consists prop-

erly of two distinct types. The first type is very rapid and is complete at the end of an hour. It corresponds in rate to that in effect, due to elastic response to increase in depth of cut, at the time work was discontinued, and comes to completion very abruptly. The second type of creep continues for days and probably for years. Quarrying operations allowed study of slow creep on gauge Nos. 4 and 5 only, and of detailed study on No. 5.

Cutting was discontinued for 15 hours 38 minutes when the first run of the cut reached 79½ inches in depth. The rock showed a continued expansion of .0014 inch on gauge No. 2 and of .0004 inch on gauge No. 4 during this interval. Both gauges were very close to the channel cut. Gauge No. 5 was set at a later date at 9 feet 2 inches farther from the channel, and during a shutdown of 63 hours 44 minutes the marble expanded .0042 inch; during the first 16 hours 36 minutes expansion amounted to .0022 inch, or an increase of more than 50 per cent over the maximum observed adjacent to the channel. Expansion by slow creep apparently is greatly retarded with increase of distance from the free surface.

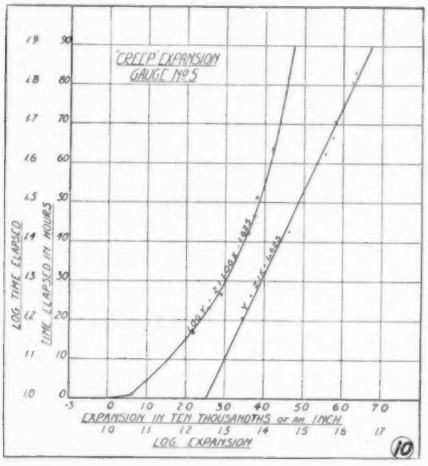

FIG. 10.—Slow creep curve for gauge No. 5. Time in hours is plotted as ordinates against expansion as abscissas.

Readings were taken three times daily while operations were discontinued for the 63 hours 44 minutes, and are plotted in Figure 10. This curve can be represented mathematically by the following equation:

$$y = 2.1x - 1.625. \qquad (1)$$

where:

$y = \text{Log } H$
$H = \text{Hours elapsed}$
$x = \text{Log } E$
$E = \text{Expansion in .0001 inch}$
$2.1 = \dfrac{\log H}{\log E}$
$1.625 = \text{intercept of the logarithmic curve with the ordinate axis}$

The curve may be represented equally well by the following equation:

$$H = E^{\frac{\log H}{\log E}} - 1.625 . \qquad (2)$$

Variation in rate of slow creep.—Slow-creep expansion goes on, when free surface is produced, at a rate independent of the rate of production of free surface. Gauge Nos. 2, 4, and 5 are placed at increasing distances from the original free surface of incompletely relieved rock. The time for expansion to take place by slow creep, after elastic response is complete, increases as an increase in the power to which expansion E is raised in equation (2). It is evident that at no great distance from a free surface this increase will become so great that relief by slow creep will be infinitely slow.

Expansion observations on gauge No. 5 indicate that elastic response expansion slows up at a very rapid rate as the distance from a free surface increases. Slow creep acts to offset in part deficient elastic response; its importance is most obvious or apparent during shutdowns overnight or Sunday.

Quarrying experience at the Valley quarry, the Florence quarries No. 5 and No. 6, and in the Pittsford Valley quarries, where this problem has been studied over a period of thirty years by the quarrymen, indicates that slow creep has been infinitely slow at distances exceeding 30 to 50 feet from an original free surface (bed rock, cave or open seam).

ORIGIN OF PRESSURE CAUSING ORIGINAL ROCK COMPRESSION

Young's modulus for marble has not been determined. The moment of inertia of the relieved rock mass is not known. Assuming

very low values for each of these unknowns, the pressure causing expansion, which is in turn equal to the pressure which compressed the rock, greatly exceeds any conceivable stress on the stone due to glacial ice. The only pressure sources which seem at all reasonable to the author are the mountain-building stresses existent when these rocks were folded into the complex groups of flowage folds found in the quarries where bursting occurs.[1] If we can determine Young's modulus for this marble, and if we can determine the moment of inertia of the rock undergoing expansion, I believe it will be possible to get some very definite figures for pressures causing mountain-folding. Furthermore, it seems possible that both the foregoing unknowns may be determined accurately in the very near future.

ADDITIONAL PROBLEMS TO BE STUDIED

The problem of rapidity of decrease of rate of creep with distance from a free surface needs additional investigation. It is expected that additional measurements may be made as soon as operations are resumed in any of the quarries. This seems to be the one line of approach to determination of the moment of inertia of the expanding rock mass.

BEARING ON RELATED PROBLEMS

The rapid rate of decrease of elastic response (instantaneous expansion) with increase in distance from a surface of relief indicates qualitatively that elastic response is almost negligible at distances over 40 feet, and slow creep becomes the more important factor at even lesser distances. Creep is very slow, and becomes rapidly increasingly so with increase in distance from the free surface; this relation may be appreciated by substituting appropriate values in the equation

$$H = E^{\log H}{}^{\log E} - \text{a constant.}$$

[1] This region has been mapped on a scale 1/6000, and structures differentiated according to their period of formation. All structures later than the period of folding (Taconic disturbance) are fracture structures and show relief of stress rather than accumulation of it. Presentation of the entire study of the marble belt would be too lengthy, and the reader is asked to accept the statement of the period of stress accumulation.

(This constant will vary with distance from the free surface and elasticity of the stone.)

The negligible effect of instantaneous expansion and the excessive slow rate of creep argues against important rises of land due to expansion as a superimposed load is removed.

Violent vibration produced by bursting when compressed rock expands past a fixed part toward a surface of relief, to beyond the elastic limit of the stone, presents many resemblances in effect and antecedent activity to earthquakes and faulting.

INCLUSIONS AND FOLIATION OF THE HARNEY PEAK GRANITE, BLACK HILLS, SOUTH DAKOTA

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ABSTRACT

Sidney Paige's contention that the granite has made room for itself by distension of the crust, and not by stoping and assimilation, is corroborated by a study of the inclusions and the foliation of the igneous rock.

MECHANICS OF INTRUSION OF THE GRANITE

In summarizing the mechanics of intrusion of the Harney Peak granite in the Black Hills, Sidney Paige[1] concludes that the magma has made room for itself by mechanical distension of the wall rocks, and that both assimilation and stoping have played an inferior rôle. In a short abstract, J. J. Runner[2] arrives at about the same results as Paige, but he is inclined to attribute more importance to assimilation than Paige does.

In 1930 the present writer had occasion to spend some sixteen days in the region, and, thanks to the courtesy of Dr. Runner, he was able to visit also some of the more distant mineral localities in the periphery of the granite mass and to discuss many questions with him in the field. It is a great pleasure to acknowledge Dr. Runner's kindness and helpful advice in the field.

In the following pages a few observations are described which may serve to discriminate further between the relative importance of mechanical distension, stoping, and assimilation of the wall rocks by the Harney Peak granite.

LOCAL GEOLOGY

The Harney Peak granite, as is well known, outcrops in the southern portion of the belt of pre-Cambrian slates and quartzose schists which form the core of the Black Hills uplift. The granite outcrops in a round area, about 10 miles in diameter, and is overlain uncon-

[1] S. Paige, "Central Black Hills," *U.S. Geol. Surv. Folio No. 219* (1925), pp. 4–5.

[2] J. J. Runner, "Intrusion Mechanics of the Harney Peak Batholithic Granite," *G. S. Amer. Bull.*, Vol. XXXIX (1928), p. 186.

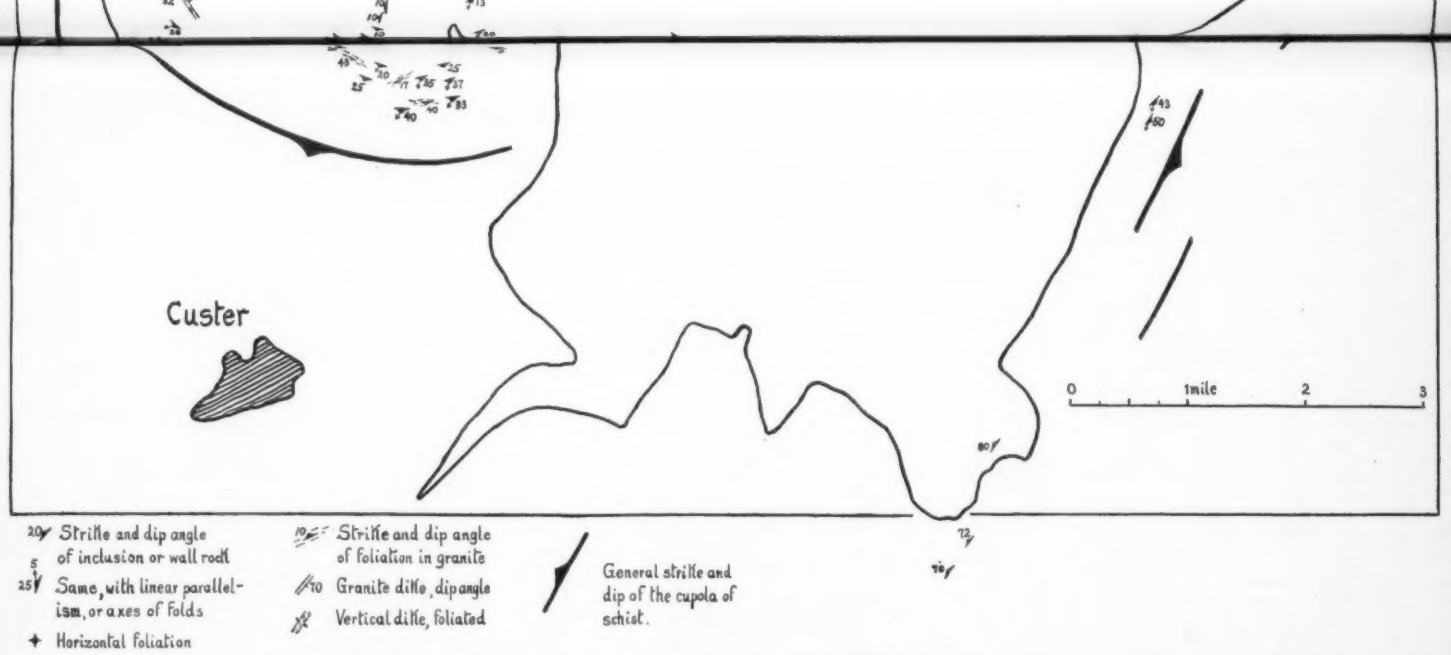

Custer
0
1 mile
2
3
20 Strike and dip angle of inclusion or wall rock
5
25 Same, with linear parallelism, or axes of folds
Horizontal foliation
Strike and dip angle of foliation in granite
Granite dike, dip angle
Vertical dike, foliated
General strike and dip of the cupola of schist.

FIG. 1.—Structure map of the Harney Peak granite area, Black Hills, South Dakota. The continuous black line represents the granite contact as shown on the geologic map, Folio 219, U.S. Geological Survey. The granite within this area is not pure, but forms an intricate system of concordant and discordant offshoots, dikes, and lenses. The intrusive is surrounded by a cupola of pre-Cambrian sediments, and hundreds of inclusions within the granite continue and conform to the cupola structure. (*S.L.* = Sylvan Lake; *H.P.* = Harney Peak.)

formably on the east and southeast side by the Cambrian Deadwood formation.

The slates and quartzose schists are strongly folded. The steeply tilted limbs dip to the east or east-northeast; and cleavage, where developed, follows the axial planes for the most part. But when approaching the Harney Peak granite, this regional dip and strike is lost completely in a perfect cupola in the core of which the granite outcrops (Figs. 1 and 2).

FIG. 2.—The cupola structure of the pre-Cambrian slates in the contact zone of the Harney Peak granite causes gentle dip slopes away from the granite core and steep escarpments facing the central peak. Looking southwest along the west flank of the granite. The top of the hill is a small sill-like granite lens, dipping with the foliation of the phyllite to the northwest. The base of the mountain is composed of the same sediments, dipping in the same direction.

Paige[1] explains this change in structure about as follows: The granite has compressed the crust so strongly from below that the previously folded sediments finally yielded to this force; and the beds, no matter what their previous strike and dip, were contorted and subsequently blotted out into the dome structure which so conspicuously encompasses the intrusive rock. The granite is sufficiently viscous to supply at once pressure and support from below. In the center of the area, the granite expanded so much that the coherence

[1] *Op. cit.*, p. 5.

of the cupola-shaped cover of sediments was severed. The rocks were disrupted, and the individual fragments have been floating on top of the granite core.

FEATURES OF THE INCLUSIONS

Paige[1] calls attention to the fact that close recumbent folds occur in the cupola of schist. The writer cannot but confirm this observation, and would add that isoclinal folds are also found in schist inclusions within the main mass of the granite. Since it is difficult, in general, to demonstrate genetic relations between magmatic intrusions and folding of the surrounding sedimentary rocks, the Harney Peak area is of especial interest, as it shows that a moving mass of magma is, indeed, capable of producing folds independent of the structure of the same rock farther away from the igneous rock. In the area under discussion, the limbs of these secondary folds slope away from the granite core, constituting the now visible cupola. Unfortunately, not sufficient data are available to determine how the axes of these secondary folds are arranged. Wegmann[2] postulates that the axes of folds should be more or less vertical along the periphery of rising mobile masses, and that all other linear structures, such as flow lines, or stretching of sedimentary wall rocks, should arrange themselves in the same way. This is actually found in salt domes[3] and in certain volcanic plugs,[4] and also along the contacts of such intrusives as moved upward faster than sidewards, e.g., in certain parts of the Sierra Nevada granodiorite.[5] But it must be remembered that the same linear structures will not conform to the direction of

[1] *Ibid.*

[2] C. E. Wegmann, "Über Diapirismus (besonders im Grundgebirge)," *Comm. Geol. de Finlande Bull. 92* (1930), pp. 58–76, especially p. 67.

[3] F. D. Vaughan, "The Five Islands, Louisiana," in *Geology of Salt Dome Oil Fields* (Amer. Assoc. Petrol. Geol. symposium, 1926), pp. 366, 368; K. Stier, "Strukturbild des Benther Salzgebirges," *Achter Jahresbericht d. Niedersächsischen geologischen Vereins zu Hannover* (Hannover, 1915).

[4] F. D. Adams, "The Monteregian Hills," *Jour. Geol.*, Vol. XI (1903), pp. 239–82, especially p. 279; F. F. Grout, "Internal Structures of Igneous Rocks, etc.," *ibid.*, XXVI (1918), pp. 439–58, with Bibliography; H. and E. Cloos, "Die Quellkuppe des Drachenfels am Rhein," *Z. f. Vulkanologie*, XI (1927), pp. 33–40.

[5] H. Cloos, *Bau und Bewegungen der Gebirge in Nordamerika, Skandinavien und Mitteleuropa* (Berlin: Gebr. Borntraeger, 1928), p. 250.

steepest ascent as soon as the mass expands in any other direction faster than upward. If, for instance, a rising dome on its journey upward should temporarily expand faster in a lateral direction, by advancing, say, into a fissure system of appreciable room capacity, or by spreading along a flat-lying zone of structural weakness, the linear elements will arrange themselves in those directions in which the material is being deflected. In this manner a very flat arch of the flow lines may ensue which does not record directly the upward motion, although the apex of such an arch does indicate the tendency of the mass to rise.

The writer has, unfortunately, only twenty-three reliable measurements of the strike and pitch of axes on hand, taken partly from the belt of schist which surrounds the granite, partly from inclusions within the granite. The projected strike shows a broad maximum in east-west to southwest-northeast, while the gentle pitch is uniformly to the west or southwest. The western half of the granite area has been examined more carefully than the eastern portion. To judge from these few data, the granite seems to have expanded laterally more readily than upward; but more measurements are necessary to decide this point definitely.

Obviously, rocks must attain a high degree of plasticity before the structure of pre-existing folds can be obliterated and a new system of isoclinal folds be imposed on the material. The mechanics whereby such transformation of structures of different ages and in different directions takes place has been studied by A. Heim,[1] Behre,[2] W. Schmidt,[3] Born,[4] B. and R. Willis,[5] Sander[6] and Scholtz;[7] and

[1] Alb. Heim, *Geologie der Schweiz*, Vol. II (1921), pp. 81–83, plate II, and p. 78.

[2] C. H. Behre, Jr., "Observations on Structures in the Slates of Northampton County, Pennsylvania," *Jour. Geol.*, Vol. XXXIV (1926), pp. 501, 502; "Slate in Northampton County, Pennsylvania," *Pa. Geol. Surv.*, 4th Series, *Bull. M 9* (1927).

[3] W. Schmidt, "Gesteinsumformung," *Denkschriften d. Naturhist. Museums zu Wien*, Vol. III (1925).

[4] A. Born, "Gefügestudien an Gesteinen des varistischen Gebirges," *Neues Jahrb. f. Miner.*, Beil.-Bd. LII, Abt. B (1925); "Über Druckschieferung im varistischen Gebirgskörper," *Fortschritte d. Geol. und Paläont*, Vol. VII, Heft 22 (1929).

[5] B. and R. Willis, *Geologic Structures* (1929), pp. 189–92.

[6] B. Sander, *Gefügekunde der Gesteine* (1930), pp. 33–53, 221, 247, 252, 253.

[7] H. Scholtz, "Das varistische Bewegungsbild," *Fortschritte d. Geol. und Paläont.*, Vol. VIII, Heft 25 (1930), pp. 241–54, plates I, II.

E. B. Knopf[1] has recently given an admirably clear résumé of these and related problems. It is in the nature of secondary adjustment movements that folds, and especially apexes of folds, become scarcer and more appressed, because the micaceous layers adjust themselves to the changing directions of compressive and rotational strain by glide movements along suitably oriented shear planes rather than by folding (Fig. 3).

FIG. 3.—Typical view of a schist inclusion in the Harney Peak granite. The layers of schist are horizontal or dip gently in random directions; they are often isoclinally folded or crumpled. Southeast spur of Harney Peak, 2 miles from the summit.

Although, in the writer's opinion, the formation of the cupola is satisfactory proof of the powerful expansion and deforming action of the present intrusive; and although it appears highly improbable that a large mass of magma would, for no conceivable reason, change its mechanism of movement during a penultimate stage of its advance, it might be argued, nevertheless, that the magma, after attaining its present site in the earth's crust, has further widened its chamber by stoping. It may be assumed that between the arrival of the granite at its present location and its final consolidation there was an intervening period during which the magma chamber, filled with a stationary liquid, grew in height by the

[1] E. B. Knopf, "Retrogressive Metamorphism and Phyllonitization, Part I," *Amer. Jour. Sci.*, Vol. XXI (1931), pp. 1–27.

downward slumping of severed blocks of the roof, while the granite took possession of the space formerly occupied by these blocks. In this case it is reasonable to assume also that the xenoliths would be assimilated by the surrounding granite the deeper down they moved.

It may be repeated that neither Paige nor Runner entertains this theory, but they do not seem to have stated in sufficient detail why these assumptions must be discarded.

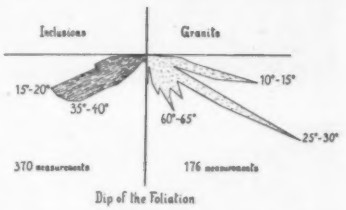


FIG. 4.—Statistical diagram of the dip angles of inclusions (left-hand side) and foliation of the Harney Peak granite (right-hand side). Distances from center indicate relative number of measurements. The schist inclusions dip uniformly at low angles from 15° to 35°; whereas steeper dip angles are observed in the foliated phases of the granite, especially where steep dikes cut across gently dipping inclusions.

The great majority of the inclusions are slabs parallel with the planes of schistosity. Now floating discoid bodies tend to arrange their longest axes subparallel with the direction of swiftest movement. If such platy xenoliths were floating downward, it must be expected that a majority of them show steep dip angles. But Runner emphasizes the *gentle dip* of most inclusions. The accompanying map shows the orientation of several hundred of them, and Figure 4 indicates the maximum dip to be between 15° and 35°, in best agreement with Runner's statement.

Because of the gentle dip angles, it cannot be assumed that the exposed xenoliths have floated downward; instead, the individual fragments have moved in subhorizontal directions. Since these planes of movements grade marginally into the cupola of the wall rock, it must be the excessive distension and expansion of the central portion of the cupola which has led to their present position.

Runner adds: "Plotting dips and strikes of inclusions reveals gentle folds."[1] During his limited visit to the region, the writer has been unable to find such features. In the central spurs of Harney Peak, which represent the structural apex of the dome, adjacent xenoliths do show gentle dips, but they strike at random. The picture resembles somewhat that of cakes of ice on the surface of agi-

[1] *Op. cit.*

FIG. 5

FIG. 6

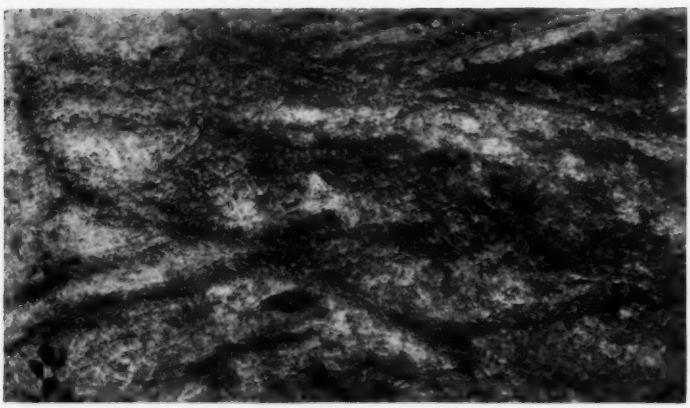


FIG. 7

FIGS. 5, 6, AND 7.—Foliated granite is traversed discordantly by dikes of foliated granite. The flow planes in the dikes are parallel to the contact walls, and cut the foliation of the wall rock at high angles. Figures 4 and 5 near top of Harney Peak; Figure 6 on west spur of the peak, ½ mile east of Sylvan Lake.

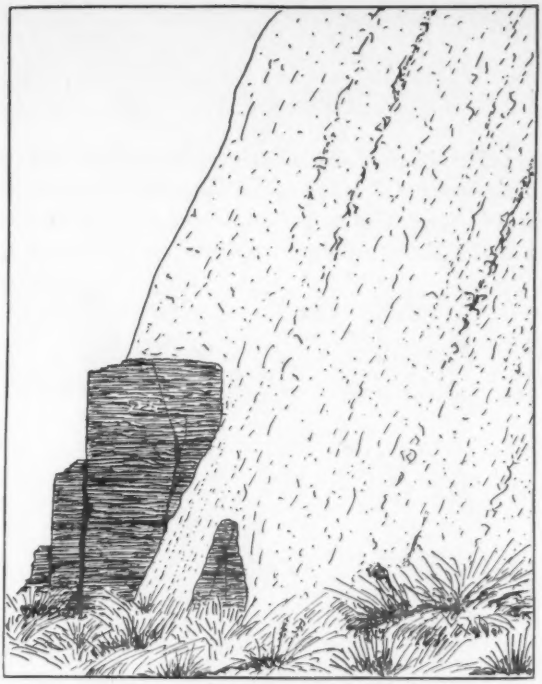


FIG. 8.—Cliff of granite, ½ mile northwest of Sylvan Lake, showing flat-lying schist inclusions, split apart by a granite dike. Foliation in the dike and in the surrounding granite wall dips steeply to the southwest, irrespective of the attitude of the xenolith.

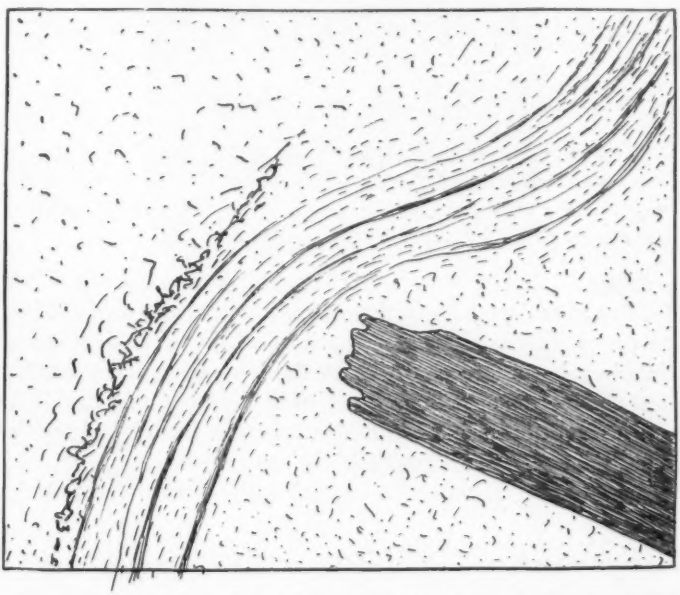


FIG. 9.—Local schlieren of mica in granite at right angles to the foliation of an adjacent schist inclusion. One mile west of Sylvan Lake. Six by five feet.

tated water. If suddenly fixed in their position, each cake would be found in a subhorizontal position, but dipping in random directions. It may be, of course, that in some parts of the Harney Peak area which the writer has not visited, such gentle anticlines or synclines

FIG. 10.—Cliff of granite, northwest of Sylvan Lake. Note the steep dip of the foliation and of pegmatite schlieren.

are suggested; but even then, these structures would be due only to a local crest or depression in the dome surface; they would not indicate pre-granitic anticlines or synclines of the schist because, as pointed out in the foregoing, the now flat-lying schist fragments represent the blotted-out remnants of isoclinal folds. In no case is the gentle attitude of the inclusions to be taken for the original position of the sediments after deposition.

Thus, as far as the writer is aware, there is not only no supporting

evidence for stoping in this magma chamber, but the well-exposed features of the inclusions of this granite are opposed to this mechanism of intrusion.

FOLIATION IN THE GRANITE

Both Runner and Paige recognize a certain amount of assimilation. While Runner considers its effect appreciable, Paige[1] points

FIG. 11.—Detail view of Figure 10

out that the *mechanical* disruption of the schistose wall rocks by the granite down to a small scale may ultimately result in such an intimate mixture of both rocks that the following chemical attack is insignificant as compared with the preceding mechanical shredding of the sediments. To this the writer would add that the visible features of such mechanically comminuted wall rocks may be almost

[1] *Op. cit.*

indistinguishable from assimilation phenomena. How, then, can we determine the relative importance of assimilation?

It can hardly be overemphasized that the parallel orientation of micaceous minerals in igneous rocks is not, in itself, sufficient evidence of magmatic assimilation. For flaky or discoid crystals, like mica, which are floating for some time in moving liquids will, for hydrodynamical reasons, orient themselves subparallel to the nearest relatively stationary wall along which the magma is moving.[1] If such a wall rock is a schist, and a plane of schistosity forms the local friction-exerting surface—a very common case in nature—then the three elements: schistosity of the wall rock, contact plane, and mineral parallelism of the adjacent igneous rock, happen to be parallel to each other. Additional proof is necessary to show that such mineral parallelism is due to assimilation.[2]

[1] This principle, and observations pertaining to it, are well known to every student of intrusive rocks. Of the numerous papers describing such features, only a few may be cited:

J. E. Spurr and G. H. Garrey, "Economic Geology of the Georgetown Quadrangle, Colorado," *U.S. Geol. Surv. Prof. Paper 63* (1908), pp. 59, 90.

F. E. Vaughan, *op. cit.*, p. 368.

F. F. Grout, *op. cit.*

J. E. Spurr, *The Ore Magmas*, Part I (1923), pp. 167–75.

C. H. Smyth, Jr., and A. F. Buddington, "Geology of the Lake Bonaparte Quadrangle," *N.Y. State Mus. Bull. 207–209* (1926), pp. 48–78.

G. Berg, "Granitstöcke und Gneismassive," *Geol. Rundschau*, Vol. IV (1913), pp. 225–28.

L. Milch, "Die primären Strukturen und Texturen der Eruptivgesteine," *Fortschritte d. Miner.*, Vol. II (1912), p. 200.

F. Rinne, "Geothermische Metamorphose und Dislokation der deutschen Kalisalzlagerstätten," *ibid.*, Vol. VI (1920), pp. 101–36.

H. Cloos, *Einführung in die tektonische Behandlung magmatischer Erscheinungen I: Das Riesengebirge in Schlesien* (1925), pp. 27–32, 51–56.

W. Riedel, "Das Aufquellen geologischer Schmelzmassen als plastischer Formänderungsvorgang, "*Neues Jahrb. f. Min.* Beil.-Bd. LXII, Abt. B (1929), pp. 151–70.

E. Seidl, *Bruch- und Fliessformen der technischen Mechanik*, Part II (1930). This author speaks of "flow stratification" (*Fliesschichtung*) and "structural stratification" (*Gefügeschichtung*) in rolled steel, and illustrates the feature (Fig. III, 2, on p. 3; Fig. V, 1, on p. 5). Professor E. C. Bingham (Department of Chemistry, Lafayette College, Easton, Pennsylvania) informed the writer in a letter recently that the same principle is made use of in the manufacture of artificial mother-of-pearl.

[2] The few xenoliths of lime silicate rock and marble which are scattered through the Harney Peak granite invite a careful investigation which may possibly decide how far the granite has been contaminated by inclusions.

Test cases for the origin of the mineral parallelism are such exposures in which contact planes of the igneous rock cut across the schistosity planes of the surrounding rock. In all such cases which have come to the writer's attention it was found that the mica crystals disregard the mineral parallelism of the surrounding rocks and that they orient themselves persistently parallel to the local contact plane, no matter whether this plane cuts the structures of the wall rocks or not. The Figures 5–9 illustrate this. Granite dikes, in-

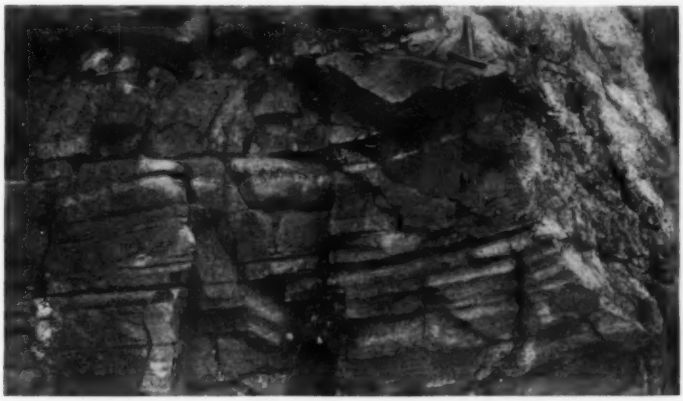


FIG. 12.—Sharp cross-cutting contact between schist inclusion and Harney Peak granite (to the right). Southeast spur of Harney Peak, 2 miles east of the Needles.

truded into slightly older granite masses in which an older set of foliation planes is already developed, cut these older flow planes; and the mica flakes within the cross-cutting dike are parallel to the contact plane of the dike (Figs. 5–7). Dikes with internal contact-parallelism cut the schistosity of inclusions at high angles (Fig. 8). Thin layers of mica curve around a projecting edge of a xenolith (Fig. 9).

Particularly instructive is the belt of granite north and northwest of Sylvan Lake. Here the foliation planes dip at 60°–70° to the south or southwest, and mica flakes within pegmatitic schlieren show the same orientation (Figs. 10–11). Schist inclusions, however, which outcrop along this zone, everywhere maintain the characteristic gentle dip (Fig. 8).

In Figure 4 dip angles of foliated granite are compared with a number of observed dips in the schist. The broad expansion of the right-hand area below dip angles of 35° reflects the parallelism in steeply dipping granite dikes which break through the cupola and xenoliths of schist with their gentle dip angles, and which disregard the mineral parallelism in the flat-lying schist.

That the Harney Peak granite has not assimilated its wall rocks appreciably is further demonstrated by the fact that the contact planes of almost all inclusions are sharp and clean-cut (Fig. 12). Elusive, gradational contact zones seem to be quite exceptional features, as far as the writer's experience goes.

Thus, the local foliation of the granite is not, per se, proof of magmatic assimilation. All test cases show the mineral parallelism to be the result, and the expression of, magma flowage along relatively stationary walls. Unless additional evidence can be produced, the effect of assimilation of the wall rocks by the Harney Peak granite must be regarded as very subordinate. It seems highly improbable that the magma chamber has been widened by this mode of magmatic attack, and the writer's field observations corroborate Paige's statement that "the granite of the Black Hills came into its present position in the main by distention of the older rock body under great pressure."[1]

[1] The scarcity of assimilation phenomena in the Harney Peak area is of special interest in view of the fact that the magma has been excessively rich in pegmatitic emanations. The locally very coarse-grained, tourmaline-bearing rock is justly called a pegmatitic granite by Paige. As it is often maintained that igneous emanations are the chief agency of assimilation, it must be borne in mind that there are also exceptions to this rule (e.g., low temperature, as assumed by Paige) and that each plutonic mass may have its individual peculiarities which necessitate and invite detailed studies of the local geological factors.

PENEPLAINS OF THE APPALACHIAN PLATEAU

HARRY M. FRIDLEY AND JOHN P. NÖLTING, JR.
West Virginia University

ABSTRACT

The ridges of the eastern part of the Appalachian Plateau of West Virginia and Pennsylvania show a marked accordance in elevation. Many of the ridge tops are broad and, in nearly all cases, are held up by resistant Carboniferous sandstones and conglomerates. To the west of the ridges, is a well-defined erosion surface developed on much weaker Upper Carboniferous shales, sandstones, and limestones. A series of projected profiles of the topography, together with structure sections, reveals an accordance of hilltops and a beveling of strata which is convincing evidence of peneplanation. This surface is evidently much younger than that marked by the ridge tops farther east.

INTRODUCTION

The crests of the higher ridges of the Appalachian Mountains have long been considered as marking the level of an ancient peneplain. This surface has been variously called the Kittatinny, Schooley, Kittatinny-Schooley, and Cretaceous peneplain. West of the ridges of the Appalachian Plateau the general level of the land is several hundred feet lower in elevation than the ridges. Many geologists have held that the two surfaces were formed at the same time, and that crustal warping was responsible for the difference in elevation of the two areas. The main purpose of this paper is to show evidence of two distinct erosion surfaces where, heretofore, only one has been generally accepted.

The index map (Fig. 1) shows the areas over which detailed study was made.

METHODS OF STUDY

Use was made of the method of projected profiles, developed by Barrell.[1]

In Figure 2, the rock structure is shown along the base line which was drawn on parallel 39° 45′. The section was projected from the north in order to show the greatest possible number of the lower hilltops. It is especially necessary to show the lower surface in the Morgantown Quadrangle, a critical area. Since the vertical in the

[1] Joseph Barrell, "The Piedmont Terraces of the Northern Appalachians," *Amer. Jour. Sci.*, 4th ser., Vol. XLIX (1920), pp. 242–45.

profiles is exaggerated about 26 times over the horizontal, any discordance in the elevation of hilltops shows up clearly. Although the extreme exaggeration tends to distort the structure, it can readily be seen that the rocks have been beveled without regard to the resistance of the beds to erosion.

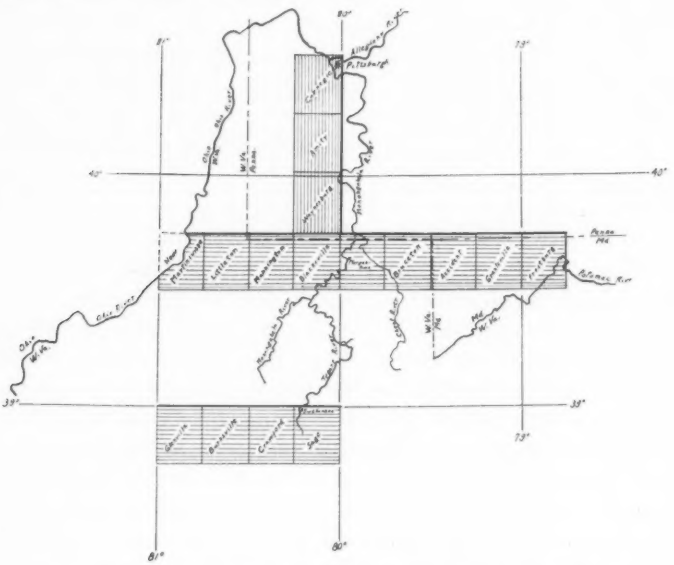


FIG. 1.—Index map. The heavy line in each section indicates the base line

To supplement the work with projected profiles, glass profiles were constructed. East-west sections were drawn across the Bruceton and Morgantown quadrangles. These profiles were made on the same scale as the projected profiles and were drawn at intervals of 1 inch (1 mile). After the profiles were transferred to glass plates, the plates were clamped together (Fig. 3).

FROSTBURG, MARYLAND—OHIO RIVER SECTION

Figure 2 shows the higher surface at the 2,800–3,000-foot level extending from the Appalachian Valley and Ridge Province in Maryland westward across the Appalachian Plateau ridges to

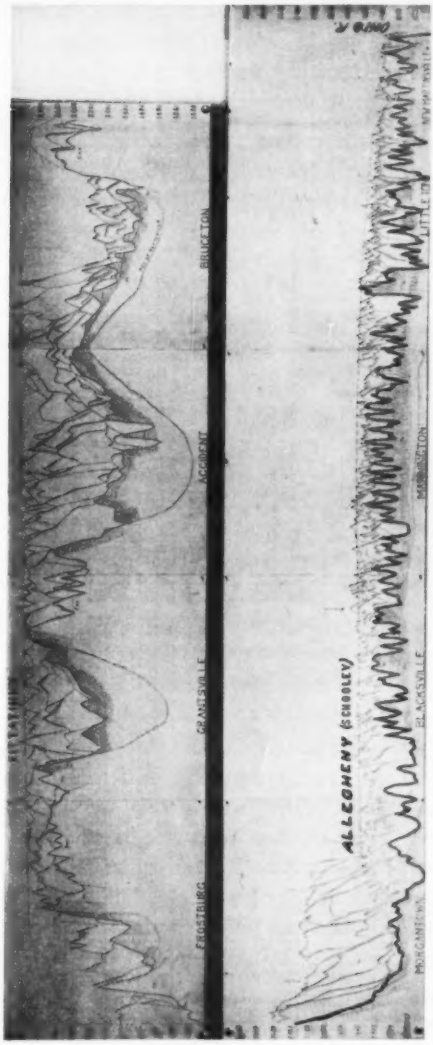


FIG. 2.—Projected profiles of the 15-minute quadrangles between Cumberland, Maryland, and the Ohio River. The structure section is along the base line which is shown on parallel 39°45′, the northern boundary of the area.

Chestnut Ridge in West Virginia. Folding, in the eastern part of the section, has brought up the stronger formations and this accounts for the fact that the territory was not reduced when the region to the west was completely peneplained. If two peneplains are to be postulated for this section, it then follows that the ridges suffered erosion during the second cycle. No doubt, those nearest the main drainage lines, such as Chestnut Ridge, were reduced below the original level.[1]

If it is assumed that the Kittatinny surface has been warped down to coincide with the lower surface to the west, considerable

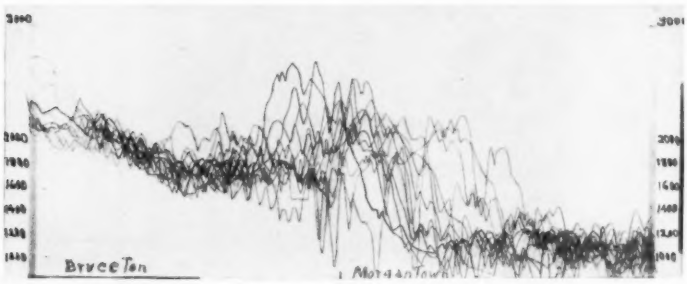


FIG. 3.—Glass profiles of the Bruceton and Morgantown quadrangles. The foreground is along the northern boundaries of the quadrangles. Twelve profiles are shown representing a territory 12 miles in depth. The vertical exaggeration is about twenty-six times.

deformation must be admitted. No evidence of recent deformation has been found here. On the other hand, if the ages of the major Appalachian peneplains are as great as they were assumed by some of our earlier investigators, then, of course, there is a greater chance of warping since peneplanation. Recent work[2] has shown that in the Appalachian region the zone of weakness has been along the "Appalachian structural front" and it is here that the greatest deformation has occurred and not on the Plateau.

[1] In Fig. 2 the top of the Pottsville series is shown as a dotted line. It is quite probable that the original Kittatinny level cut across the top of the Pottsville in Chestnut Ridge. Note Bruceton and Morgantown quadrangles.

[2] Paul H. Price, "The Appalachian Structural Front," *Jour. Geol.*, Vol. XXXIX (1931), pp. 24–44.

As to the age of peneplains the works of Shaw,[1] Ashley,[2] and others offer convincing evidence that none of the Appalachian peneplains are older than Tertiary.

The lower peneplain "Allegheny,"[3] is not well developed east of Chestnut Ridge in northern West Virginia and southern Pennsylvania. In the vicinity of Grafton, West Virginia, where Chestnut Ridge is less prominent, the Allegheny surface can be traced eastward in the Tygart and Three Forks basins. It appears that the country around Masontown, West Virginia, was worn down to the stage of late maturity only, while the country west of Chestnut Ridge was peneplained. Convincing proof has been offered that Decker's Creek has recently robbed the headwaters of the south-flowing branch of the Three Fork–Tygart system.[4] Thus the drainage from the Masontown area now flows over a distance of 14 miles to Morgantown; whereas formerly it was required to travel over a distance of nearly 100 miles to reach the same place on the Monongahela River. Cheat River cuts through Chestnut Ridge in a deep, narrow gorge, indicating a comparatively recent shift in drainage. The basin between Chestnut Ridge and Briery Mountain has a general slope toward the south rather than toward the northwest in the direction of the Cheat River outlet.

Between the higher Plateau ridges the topography has been reduced fairly uniformly to elevations varying from 2,000 to 2,400 feet. It is very likely that the main streams of the interridge areas had approached baselevel when the Allegheny peneplain was completed.

Reger[5] describes the Weverton peneplain as being represented by the crest of Knobley Mountain in Mineral County, West Virginia, at an elevation of 1,700–1,800 feet and by the Fore Knobs, near Keyser, at an elevation of 2,400 feet. In looking eastward from the

[1] E. W. Shaw, "Ages of Peneplains of the Appalachian Province," *Bull. XXIX, Geol. Soc. Amer.* (1918), pp. 575–86.

[2] George H. Ashley, "Age of the Appalachian Peneplains," *Bull. Geol. Soc. Amer.*, Vol. XLI, No. 4, pp. 695–700.

[3] The name Allegheny was suggested by Dr. George H. Ashley in 1929. Private correspondence.

[4] John P. Nölting, Jr., "Drainage Changes in the Headwater Region of Deckers Creek," *Proc. W.Va. Acad. Sci.*, Vol. V (1931).

[5] David B. Reger, "Mineral and Grant Counties," *W.Va. Geol. Surv.* (1924), pp. 31–32.

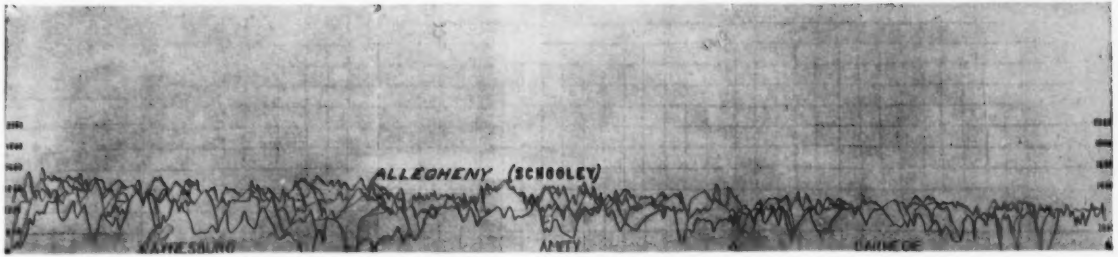


FIG. 4.—Projected profiles of Waynesburg-Carnegie section. Base line along eastern boundaries of quadrangles, meridian 80°

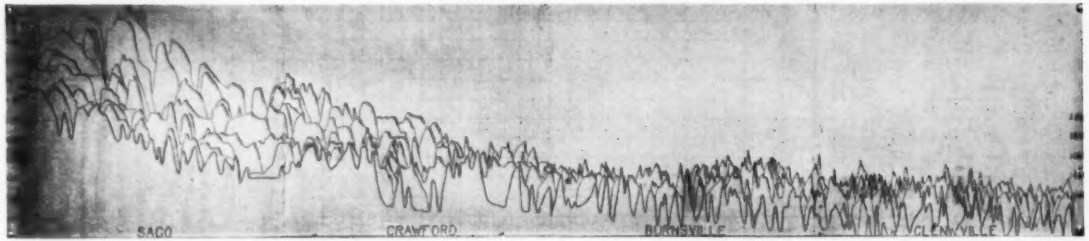


FIG. 5.—Projected profiles of Sago-Glenville section. Base line along northern boundaries of quadrangles, parallel 39°

Allegheny front, one is impressed with the appearance of two distinct levels, one at the elevation of the Allegheny front and the other 600–800 feet lower. The relation of the two peneplains in the east and west indicates that the Allegheny and Weverton surfaces are probably the same.

THE WAYNESBURG-CARNEGIE SECTION

The Allegheny peneplain is quite definitely shown in Figure 4, at an elevation of about 1,500 feet at Waynesburg and a little less than 1,300 feet near Pittsburgh. The well-marked surface around Pittsburgh has been called the Harrisburg peneplain by Campbell,[1] Leighton,[2] and others.

Evidence has been offered in a previous article by one of the writers[3] that this is a much older surface than the Harrisburg. This peneplain can readily be traced from Pittsburgh northward to New York and eastward to the Catskill Mountains.

SAGO-GLENVILLE SECTION

The break between the two surfaces, Kittatinny and Allegheny, is not quite so clear in the Sago-Glenville areas as it is farther north, but from the profiles it is difficult to find evidence of a single surface having been so warped that the higher surface coincides with the lower well-marked level in the Glenville Quadrangle.

CONCLUSIONS

The ridge tops of the eastern Appalachian Plateau represent the Kittatinny peneplain which can be traced across the higher ridges of the folded Appalachians. This peneplain is older than, and distinct from, the "Allegheny" erosion surface which has been well developed and is easily discerned in western West Virginia, western Pennsylvania, and southern New York. The name Kittatinny, instead of Schooley, should be applied to the highest erosion surface of the Appalachians, because it is questionable whether or not the crest of Schooley Mountain represents this peneplain.

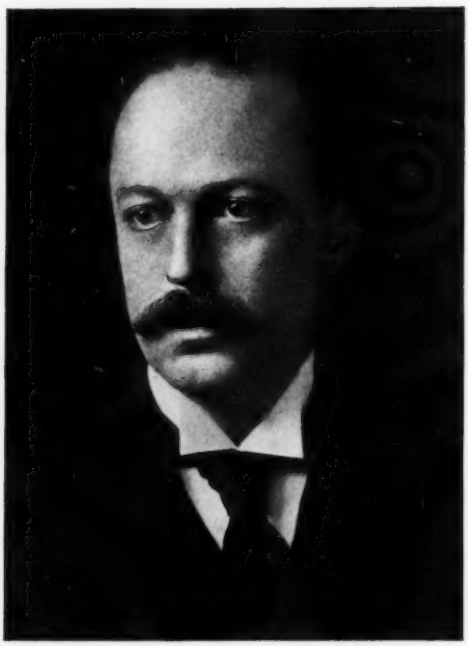
[1] M. R. Campbell, "Geographic Development of Northern Pennsylvania and Southern New York," *Bull. Geol. Soc. Amer.*, Vol. XIV (1903), p. 292.

[2] Henry Leighton, "The Geology of Pittsburgh and Its Environs: a Popular Account of the General Geologic Features of the Region," *Carnegie Mus., Annals*, Vol. XVII, No. 1 (1926), pp. 91–162.

[3] Harry M. Fridley, "Identification of Erosion Surfaces in South-Central New York," *Jour. Geol.*, Vol. XXXVII (1929), pp. 113–14.

RICHARD ALEXANDER FULLERTON PENROSE, JR.
1863–1931

In the passing of Dr. Penrose on July 31, 1931, the *Journal of Geology* lost one of its original editors and its greatest patron. Ever since its initial appearance at the beginning of 1893, the *Journal* has



been largely what its originators made it. To the group of first editors, T. C. Chamberlin, R. D. Salisbury, J. P. Iddings, R. A. F. Penrose, Jr., C. R. Van Hise, C. D. Walcott, W. H. Holmes, and George Baur, the *Journal* owes its greatest debt. To most of these distinguished founders it has acknowledged, in a way, its appreciation and lasting obligation. Penrose was the last to leave the fold,

serving as active editor and later as associate editor longer than any of the others. Happily the fruits of what he did in this long period of service and the spirit of the man himself live on with the *Journal* as its heritage. Even more tangibly, perhaps, his great helpfulness to the *Journal* is now to continue indefinitely through the magnificent provision made in his will for its future growth and development.

R. A. F. Penrose, Jr., was one of four brothers who brought new distinction to an illustrious family, since early colonial days one of the most prominent in Pennsylvania. His father, in reverence for whose memory he remained always junior, filled the chair of obstetrics at the University of Pennsylvania with great success from 1863 till his voluntary retirement in 1889.

Graduating from Harvard, *summa cum laude*, in 1884, Richard Jr. continued in geology under the inspiration of Shaler, submitting two years later his Doctor's thesis on "The Nature and Origin of Deposits of Phosphate of Lime" which was subsequently published as *Bulletin No. 46* of the United States Geological Survey. Soon thereafter he was engaged in important studies for the geological surveys of Texas and Arkansas and prepared various reports among which his treatise on manganese was an outstanding contribution.

When the University of Chicago was organized and the best available talent sought, Penrose was called to the new institution as Associate Professor of Economic Geology. Fitting ideally into the new group, he participated actively in the development of the rapidly advancing department of geology. In 1895 he was promoted to a full professorship. The year before he had been appointed Special Geologist on the United States Geological Survey to examine and report on the gold district of Cripple Creek, Colorado. The camp was then young and his admirable report ("The Mining Geology of the Cripple Creek District, Colorado," *U.S.G.S., 16th Ann. Rept.*, Part II [1895], pp. 111–209) appeared in time to be of great value as a guide to further development. But unfortunately for the University, as his horizon expanded, he became more and more involved in active mining operations and felt obliged in consequence to withdraw more and more from academic work. He was one of the founders of the Commonwealth Mining and Milling Company, operating in

Arizona, and became its first president. Resigning from this very successful enterprise in 1903, he played a leading part in developing the disseminated low-grade copper deposit in Bingham Canyon, Utah, once called "the greatest wildcat in the State," into the famous Utah Copper Company workings, the first of the great porphyry copper mines and one of the most striking successes in the history of mining. The time required by these large undertakings, however, necessitated giving up professorial work altogether; yet so highly was he esteemed at Chicago that he was continued as the nominal professor of economic geology till 1911 in the hope that he might find it possible to return to the department. But that was not to be.

To the first volume of the *Journal of Geology*, which started strongly with articles on the broad, fundamental problems of geology by men of recognized standing, Penrose contributed a discussion of "The Chemical Relation of Iron and Manganese in Sedimentary Rocks." His thorough treatment of the many factors and principles governing solution and precipitation of these important elements made this a work of much scientific and practical value. In the second volume of the *Journal* appeared his studies on "The Superficial Alteration of Ore Deposits." The influence of this was widely felt, and it was, in fact, one of the studies out of which ultimately came our present ideas of secondary enrichment. Later his writings dealt more largely with selected mining districts arising from his almost unrivaled personal acquaintance with the principal mining regions of the globe.

One of his ambitions was to write a book on ore deposits and with that end in view he set out to see all the important ore deposits of the world. He was an early visitor to Rio Tinto and the South American copper districts, studied the gold placers of Tierra del Fuego when they first attracted attention, and crossed Siberia before the Trans-Siberian railway was completed. Most of the necessary traveling had already been done, though shortly before his death he was planning to go again to Burma. The great pity is that the book was never finished; with his capacity for great pains and scrupulous accuracy, it would undoubtedly have been a production of exceptional merit. Its lack of completion must be charged to the prodigality with which

he gave his time and energy to the multitudinous causes in which he became interested. His helpfulness in so many different lines of endeavor was truly at the expense of his own scientific work. But therein probably lay even greater usefulness than in the more restricted field of personal research.

Dr. Penrose was a member of the American Philosophical Society (at different times member of the Council and the Publication Committee); Fellow of the Geological Society of America (member of the Council 1914–16, First Vice-President 1919, President 1930); more than any other man the founder of the Society of Economic Geologists and first President (1920–21); Fellow of the American Geographical Society, the Royal Geographical Society of London, the American Association for the Advancement of Science, and of the Colorado Scientific Society; President of the Academy of Natural Sciences of Philadelphia (1922–26); member of the Franklin Institute of Philadelphia, the Washington Academy of Sciences, Geological Society of Washington, Hakluyt Society of England, Mining and Metallurgical Society of America (member of Council 1910–31), American Institute of Mining Engineers, Zoölogical Society of Philadelphia, University Museum (Philadelphia), American Museum of Natural History, New York, and the Historical Society of Philadelphia. He was a member of the board of trustees of the University of Pennsylvania from 1911 to 1927; trustee of the Library of Philadelphia; member of the Fairmount Park Commission of Philadelphia; and served on various committees of the Division of Geology and Geography of the National Research Council. Several railroads and various mining companies also profited from his wise counsel as a director.

As notable as his splendid achievements was the lovable nature of the man. Because of an extreme modesty these important accomplishments seemed on personal contact to fade away into the background before the warm unostentatious friendliness and sterling qualities of his strong personality. His old chief at Chicago, till the end of his long life, treasured his association with Penrose as among his most cherished recollections. Many beautiful expressions of this lasting affection appear in the letters between the two men. And so it was with many other colleagues and associates of Dr. Penrose, to

whom his passing has come with the force of a personal bereavement.

By the terms of his will the financial fruits of his successful life, like his geological work, are to further the advancement of his beloved science. The *Journal of Geology* joins its sister publication, *Economic Geology*, in expressing its great appreciation of the provisions, so replete with future usefulness, which Dr. Penrose has made for the dissemination of geologic knowledge. More than this, the astonishing sum to be shared equally by the Geological Society of America and the American Philosophical Society make Penrose, as Professor Schuchert has said, "the greatest patron of American Geology."

ROLLIN T. CHAMBERLIN

REVIEWS

TO THE EDITOR:

I wish to correct two wrong impressions given in the recent review of *Structure of Typical American Oil Fields*, published by the American Association of Petroleum Geologists (*Jour. Geol.*, Vol. XXXIX [1931], pp. 691–92). Your reviewer states that "the thirty papers in the first and the forty in the second volume were presented at the 1927 meeting of the American Association of Petroleum Geologists." As a matter of fact—and this could have been readily determined by reference to the articles—one paper was presented before the 1926 meeting; 46 before the 1927 meeting; and 2 before the 1928 meeting. *Twenty-one* of the papers were not presented before any Association meeting. I might add also, for those who have claimed that these volumes are merely reprints from the Association *Bulletin*, that only 18 of the 70 papers appeared in the *Bulletin*. *Fifty-two papers were original contributions to the Structure Symposium.*

Referring again to your review, I wish to correct the impression that Mr. Hull should receive *all* credit for editing these volumes. Much credit is due to Mr. Hull, as remarked by Sidney Powers in his Prefatory Note to Volume I; but to Sidney Powers belongs an immense amount of credit for soliciting the papers, correcting them, correlating and co-ordinating them, and bringing them together into a systematic and well-balanced group, a task most difficult and usually most thankless. To Sidney Powers the geological profession owes a big debt of gratitude for the accomplishment of this work. It is only because of his modesty and his intense eagerness to serve his profession that his large part in accomplishing the completion of these two volumes has not been made more evident.

F. H. LAHEE

REPLY TO DISCUSSION OF REVIEW OF *GEOLOGY OF THE McCALLS FERRY-QUARRYVILLE DISTRICT, PENNSYLVANIA*

In the *Journal of Geology* for February–March, 1931, E. B. Knopf and A. I. Jonas discussed a review[1] by me of their bulletin on the McCalls Ferry-Quarryville District.[2] I am grateful to Dr. Knopf and Dr. Jonas for pointing out an unintentional bit of injustice which my review does

[1] *Jour. Geol.*, Vol. XXXVIII (1930), p. 42. [2] *U.S. Geol. Surv. Bull. 799* (1929).

them. I stated that the idea of continuity and identity of the Octorara schist with the Wissahickon gneiss was proposed by A. C. Hawkins; whereas, as the authors point out, their views, as embodied in *Bulletin 799*, had already been published in the *American Journal of Science* in 1923. My error was partly due to the circumstance that in their earlier paper there is no explicit statement that they no longer considered the Octorara schist a different formation from the Wissahickon; nor, in discussing the metamorphism of the latter, is it definitely stated that its albite-chlorite facies includes the Octorara schist.[1] I should not, however, in reading Hawkins' paper at the time of its publication, have overlooked his statement[2] that Knopf and Jonas call the phyllite overlying the Chester Valley limestone "pre-Cambrian"; and I sincerely regret such statements in the review as might imply that proper credit was overlooked.

I am also indebted to the authors for pointing out a statement in the review which was not adequately qualified. The assertion that the authors "admit that they failed to find any direct evidence of faulting along the upper contact of the limestone" was prompted by the words, "The existence of the overthrust is difficult to demonstrate on account of the fact that the fault plane itself has been seen in only a few localities and there the relations are obscure";[3] "But the *absence of structural evidence of faulting* [my italics] along the overthrust plane is offset by the fact . . . ." (here follows the description of a discordant contact cited in the discussion); and, "The absence of dislocation phenomena in the few localities where the thrust plane has been seen. . . . ."[4] These quotations will show what was intended in my too ambiguous use of the phrase "direct evidence." The authors are correct in pointing out that they have submitted stratigraphic evidence of thrusting.

In suggesting that the possibility of Paleozoic instead of pre-Cambrian age for the Glenarm series still deserves consideration, I was obliged by limitation of space to leave partially unexpressed my high regard for the excellent quality of geological work that the authors have done in a district presenting problems of a most difficult type.

H. E. McKinstry

[1] *Amer. Jour. Sci.*, Vol. V, 5th Ser. (1923), pp. 40–64. In the Introduction, the writers summarize (p. 42) their earlier conclusion that the Wissahickon gneiss is a different formation from the Octorara schist. In the body of the article the only mention of Octorara schist is on page 46: "It [the Peters Creek] comprises part of what was originally mapped as Wissahickon gneiss and *part of* the Octorara schist" (my italics).

[2] *Ibid.*, Vol. VII, 5th Ser. (1924), pp. 355, 356.

[3] *U.S. Geol. Surv. Bull. 799*, p 35.

[4] *Ibid.*, p. 88.

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